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AN ECONOMIC FEASIBILITY STUDY OF COAL DESULFURIZATION

VOLUME II

A Study for the
Division of Air Pollution
Public Health Service
U.S. Department of Health, Education and Welfare

Contract No. PH 86-65-29

by

Paul Weir Company, Inc.
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ECONOMIC FEASIBILITY STUDY
OF
COAL DESULFURIZATION

SECTION 1.0 Introduction

1.1 Object and Scope of Report

Under the Clean Air Act (Public Law 88-206, 88th Congress), the U.S. Department of Health, Education and Welfare is charged with the responsibility of expediting research into the desulfurization of fuels. The Act provides for the letting of contracts to complement research activities performed directly by the Public Health Service of the Department as well as by other organizations under research grants.

Under contract to the Public Health Service, through the Division of Air Pollution, the Paul Weir Company has investigated the feasibility of reducing the sulfur content of coals by generally known coal preparation methods together with known costs through case studies. This has been under Contract No. PH 86-65-29, dated December 15, 1964.

By "desulfurization" in this study, is meant the removal or lowering of the sulfur content of American coals through known methods of crushing, washing, and various processes other than changing the solid nature of coal, such as through chemical decomposition into gaseous and liquid products. This study is not involved with the removal of sulfur from flue gases.

Since the main source of sulfur dioxide air pollution from coal is the result of its use as "steam" coal, this study largely concerns itself with United States steam coals as distinct from coals used for metallurgical or coking purposes.

Work under this contract involved a study of the production, distribution and end use of bituminous and lignitic coals; a study of the proximate analyses of the major coal beds in the United States; a study of the sulfur forms in these major coal beds; an estimate of the reserves and location of high sulfur coal beds; case studies of current coal preparation practices in preparing steam coals including current costs and suggested methods of coal preparation, using the most modern available equipment together with an estimate of costs for such treatment based upon a 1,000 ton per hour capacity plant.

1.2 Acknowledgements

Information for this study and report comes from many sources. In addition to literature and statistical data research, discussions were held with many of the leaders in the coal industry involved in the mining, preparation and use of coal as well as research groups and universities. A partial list of references is given in Section 6.0. Others are listed on the various tables, as they occur.

Information from the U.S. Bureau of Mines, published and unpublished data, was freely drawn upon as well as verbal discussions with Bureau personnel involved in this area of work. Numerous coal companies willingly gave test and operating data of vital importance.

The Paul Weir Company project engineer for this study was Mr. Raymond E. Zimmerman, a Vice President of the Company. He was assisted in the collection and preparing of data for the report by other company personnel, particularly Mr. George H. Roman. The guidance of Dr. Clayton G. Ball, President of the Paul Weir Company, is gratefully acknowledged.

Throughout the study, research and preparation of this report, close liaison has been kept with responsible personnel of the Division of Air Pollution, Public Health Service, and frequent conferences and progress reports were made. The Paul Weir Company worked through Mr. Paul W. Spaite, Deputy Chief of the Engineering R&D Section, Laboratory of Engineering and Physical Sciences, Division of Air Pollution, who is directly involved in the supervision of this contract, and Dr. J. H. Ludwig, Chief, Engineering and Physical Sciences. The advice of Dr. F. A. Rohrman, Staff Advisor to the Division of Air Pollution, was helpful at these joint conferences. The cooperation of all these gentlemen is gratefully acknowledged.

SECTION 2.0 Summary

2.1 Of the 435,000,000 tons of bituminous and lignite coal consumed in the United States in 1964, more than half was consumed by electric utilities for power generation. It has been estimated that by 1970, approximately 600,000,000 tons will be consumed of which at least 64 percent will be used by electric utilities.

There will be a gradual decline in coal used for household and allied uses and but a moderate increase in coal for coke making. Eventually, (beyond 1970), there will be a gradual increase in the uses of coal, assuming an economic breakthrough for gasification and production of liquid fuels.

2.2 The largest consuming region for coal is the East-North Central or Great Lakes region. Other large consuming areas are the Middle Atlantic and South Atlantic. The United States is divided into 23 coal producing districts. All the major coal beds together with their proximate analyses and sulfur contents are listed in this report.

2.3 In order to narrow down the number of coal beds for detailed study, we have arbitrarily used 2 percent total sulfur as the lower limit. There are about 47 major coal beds whose sulfur content will run 2 percent or higher. The total estimated minable reserves of these high sulfur coals are estimated as 75 billion tons.

The largest proportion of these high sulfur coals are in the states of Ohio, Indiana, Illinois and West Kentucky, the producers shipping the bulk of these coals to electric utilities.

2.4 A detailed investigation was made through literature search, direct contact with the U.S. Bureau of Mines, universities and coal companies concerning the nature of the various coal beds, their location, quality and, particularly, sulfur distribution.

Our research shows that although there are considerable data on some coal beds, particularly in the Appalachian area, there is a serious lack of information, particularly sulfur distribution, for coals in the midwestern fields. This has been a handicap in this study since the midwestern fields are prime suppliers of high sulfur steam coals.

2.5 Sulfur occurs in three forms, organic, sulfate and pyritic. The amount of sulfate sulfur is very small and is usually disregarded or added to the organic. Organic sulfur, which is inherent in the coal substance, cannot be removed by physical means. In some coals organic sulfur may in itself be over 2 percent.

Pyritic sulfur comes in many forms and particle sizes. The coarser particles are relatively easy to remove while some are so finely disseminated that a proportion could almost be classed as inherent.

There is no such thing as a standard sulfur content for each coal bed. The amount and variety of sulfur forms will vary in the same coal bed from one area to another. The sulfur will vary in different layers of the bed from top to bottom.

It is, therefore, difficult to draw conclusions as to potential sulfur reduction for even a single coal bed without further pinpointing the location as well.

Nevertheless, there are some areas where the coals appear to be more amenable to reducing sulfur and others where reduction may be quite limited. It was found, for example, that most Central Pennsylvania coal beds can by proper crushing and cleaning be reduced to a reasonable level. There are some midwestern coals, however, where even with fine grinding, the sulfur level cannot be greatly reduced.

Generally, the higher the total sulfur, the higher the pyritic content. Also, generally, the percentage of sulfur reduction is greater with high sulfur than with low sulfur coals.

2.6 The removal of pyrite involves crushing coal to liberate pyrite particles. In some cases crushing to 1-1/2 inches may suffice. In many other cases only extreme fine grinding will bring about liberation. This may be down to 30 mesh in size or even to 200 mesh.

Most coal cleaning processes make use of the specific gravity relationship between coal (which is lightweight) and rock or pyrite, which is heavier. "Float and sink" analyses at various specific gravities are made to determine a coal's "washability", that is, its ability to separate from its impurities without undue loss. Various types of equipment have been designed to simulate this specific gravity relationship in practice. All commercial processes use water as the medium or a mixture of sand or magnetite and water. The exception is froth flotation which is used to treat coal finer than 30 mesh and makes use of physical-chemical reactions at the coal interface to separate coal from its impurities. However, even froth flotation uses water as the carrying medium. Air tables may be used, but are not efficient.

To date, there is no known economical method of separation while coal is in the dry state, although, a rough pyrite concentration can be made by air classifiers; this method holds promise.

2.7 Six case studies of existing preparation plants are presented together with their flow sheets and coal characteristics, and an estimate of their capital and operating costs. Using a separating density of 1.60 (common in steam coal cleaning plants), washing costs varied from $0.25 per ton to as high as $0.532 per ton of product. Costs were also estimated for washing these coals at 1.45 and 1.35 specific gravities. At these lower gravities, costs increase in proportion to coal yield loss and efficiency of separation.

In none of these plants is the coal crushed finer than 1-1/2 inches and, generally, they are over 3 inches. In none of the six cases did the sulfur drop below 2 percent at the 1.60 specific gravity separation.

In the six case studies, total costs f.o.b. mine in cents per million Btu at the 1.60 specific gravity separating point varied from a low of 13.5 to 17.7 cents. At the 1.35 specific gravity range, it varied from 18.4 to 22 cents.

Few if any of the existing coal preparation plants on steam coal are actually designed for maximum sulfur reduction. In fact, large tonnages of coal to electric utilities are not cleaned in any way and many plants do only a simple job of scalping off the larger pieces of rock.

2.8 For these reasons, submitted in this study are three proposed methods for cleaning coal that attempts to incorporate the most modern techniques consistent with costs and crushing the coal to acceptable limits for handling. One plan assumes rail or barge transportation and crushes the coal to minus 3/8 inches; another plan crushes the coal to minus 14 mesh for pipelining as a slurry; while another plan makes a final crushing at the power plant air classifiers and recleans the high sulfur fraction.

It is estimated that Plan "A", where the maximum product size is 3/8 inches, coal can be prepared for $0.487 per ton of product. Plan "B", where the coal is washed first at a preparation plant and pulverized and air classified at the power plant with part returned for rewashing, the preparation costs would be $0.532 per ton of product. Plan "C", where the coal is washed and crushed to 14 mesh and kept in a slurry suitable for pipelining, the preparation costs are estimated to be $0.416 per ton of product.

Although these preparation costs are somewhat higher than many preparation costs for steam coal, they are not higher than for coal prepared for metallurgical markets and, assuming $2.45 per ton for initial mining costs, the f.o.b. costs per million Btu range from 14.8 to 15.3 cents for 12,000 Btu per pound coal.

The actual sulfur levels achieved by any of these plans will depend upon the sulfur distribution in the particular coal seam. There is no data available on the effect of fine crushing of Illinois and West Kentucky coals, except one test made by Bituminous Coal Research on the Illinois No. 6 bed, and this particular coal did not show a sulfur liberation. Many other coals, however, can be reduced to below the 2.00 percent sulfur level by a combination of crushing and proper coal preparation techniques.

2.9 Although it is not the purpose of this study to investigate the possibilities of treating high pyritic content rejects from coal preparation plants, it is our belief that such study should be made to determine the most suitable method of concentrating pyrite itself and processing it for iron and sulfur recovery. A suggested process flow sheet is given, to show what might be accomplished by fluo solid roasting and reducing followed by magnetic separation and sulfuric acid recovery.

2.10 One of the results of this investigation is that it shows there are many gaps of information that have to be explored before a final feasibility study can be completed that would cover all the aspects of coal desulfurization by coal preparation methods. Some suggested fields of required investigation are:

(a) Investigation of the sulfur forms and distribution of all major high sulfur coal beds in the United States, including the effect of fine grinding for pyritic liberation.

(b) Test data on the cleanability or washability of these coals.

(c) Research into better methods of removing pyrite from coal other than by specific gravity separation, thus improving coal yield while at the same time eliminating pyrite.

(d) An investigation of the economics of recovering both iron and sulfur from high pyritic content coals.

SECTION 4.0 Case Studies

4.1 Scope of Case Studies and Limitations

An attempt is made to describe actual coal preparation plants in the United States washing high sulfur coals for steam coal production. Six case studies are presented. One could hardly say that the average facilities for preparing steam coal, and in particular fuel for electric utilities, are as good as the ones presented. The purpose here is to describe some of the better practices in accordance with standard preparation equipment currently being used.

As is well-known much of the electric utility coal is not cleaned at all, but is received as raw (usually crushed or screened to minus 1-1/2 inches) run-of-mine. Some of it is partially cleaned to remove the larger pieces of rock. Electric generating stations placed at the mine site are usually fed raw or partially cleaned crushed coal.

Complete preparation plants usually produce other sizes such as various sizes of stoker and nut or furnace coal, shipping the finer sizes or various composites to the electric utilities. As the markets for these various sizes diminish, the trend is towards one product -- utility coal, and with this is combined the unit or integral train concept for lower rail transportation costs.

In each of the case studies actual plant costs are used, where possible. There is a wide divergence in both capital and operating costs. There are various reasons for this such as, differences in type of equipment used, location, capacity, sizes of coal produced, degree of cleaning, handling of fines, thermal drying, extent of automation and the age of the plant.

It was impossible to get standardized data for all the six studies. The actual density of separation is generally unknown, and is varied to suit market conditions and the nature of the coal. Since most plants washing coal for the steam trade separate at 1.60 specific gravity or higher, for the purposes of this study, it was thought better to show cost relationship at a 1.60 specific gravity of separation and then, based upon available washability data, indicate what the costs would be at the lower densities of 1.45 and 1.35, since the lower densities would indicate the minimum sulfur content for the sizes of coal treated.

In all the case studies, the coals were not crushed finer than 1-1/2 inches and usually the top particle size was up to 3-1/2 inches to 7 inches. None of the companies have explored the effect on sulfur reduction by crushing to finer sizes.

Some washability data are shown for various coal sizes, but they are the result of natural screen sizes as distinct from crushing the total coal to these sizes.

The increase in costs at 1.45 and 1.35 are the result of directly relating the loss of coal yield plus the expected loss in efficiency of separation that usually occurs at these lower gravities. In fact, none of these plants are equipped for operating at 1.35 specific gravity (this would require a complex heavy media system and froth flotation). Most of them, as designed, would have difficulty cleaning coal at 1.45 which is not an uncommon gravity for coal preparation plants treating coal for metallurgical purposes.

Nevertheless, the loss in yield or coal recovery by operating at the lower densities would hold true, in accordance with float and sink analyses, regardless of what equipment was used, at least until someone can devise a scheme for separating pyrite from coal other than by present known methods of coal washing.

There is, of course, some credits in cleaning coal at lower densities. Most coals have to meet certain market requirements as to ash and Btu contents and lower ash and higher Btu values result with more efficient and lower density cleaning. In addition to stoker, retail and other markets, electric utility companies have specifications for coal based on ash, moisture and particularly Btu values, usually with penalty and bonus clauses above or below set figures.

The actual credits for increased Btu value (the most important factor) will vary with individual contracts, being also related to transportation costs and delivered prices.

An average of various contracts show a credit of $0.03 for each 100 Btu increase over the pre-set quality. This is used in our calculations, however, it is emphasized that this credit value will vary widely depending upon local conditions and particularly transportation distances to power plants.

In the case studies presented in this report, the Btu credit is reflected in the costs given per million Btu at the mine. These are also credited in the sulfur reduction curves shown for each case study.

Of the six case studies, three are of plants in the Illinois coal fields. The reasons for this is the availability of data; that Illinois produces large amounts of steam coal; and that its coals are high in sulfur. They also reflect similar conditions in Indiana. The other studies are one each from West Kentucky, Ohio and Western Pennsylvania.

The West Kentucky (Mine "D") study is from a mine cleaning the No. 9 bed. To this study is also added washability data on the Nos. 11 and 12 beds for purposes of comparing possible sulfur levels in those beds.

4.2 Case Study, Mine "A"

Mine "A" is an underground mine in Franklin County, Illinois, mining the Illinois No. 6 bed. This is a relatively new plant (five years) and designed to prepare various commercial sizes as well as "slack" for electric utilities. It can process 700 tons per hour of raw coal. It has a heavy media process for the coarse coal, Deister tables for the fine sizes and thermal heat dryers. This would be considered a better than average plant for ordinary steam coal production in the midwest area. Mining costs are estimated to be $2.75 per ton before cleaning.

On a cost per million Btu and with "as received" Btu value of 11,900, f.o.b. costs at the mine are 14.6 cents for the 1.60 specific gravity separation, 15.5 cents at 1.45 and 18.4 cents at 1.35 specific gravity. This includes allowance for the increase in Btu value as a result of lowering the ash content of the coal at the lower operating gravities.

The head or raw coal sulfur content of this coal is 2.93 percent. The 1.60 operating density reduces it only to 2.43 percent and at 1.35 down to 2.20 percent. The organic sulfur in this coal is 1.85 percent.

The result of finer crushing of this coal (beyond 3-1/2 inches) is not available. The Btu cost versus sulfur content is illustrated in Figure No. 18. Table No. 10 gives typical float and sink data for the 3-1/2" x 0 composite, and Tables Nos. 11, 12 and 13 give similar data for various size fractions of the coal. It should be pointed out that these size fractions are the natural sizes and not the result of crushing run-of-mine coal down to these sizes. Figures Nos. 19, 20, 21 and 22, show the washability curves and Figure No. 23, illustrates the flow sheet for the plant.

Mining costs are the total mining costs up to the handling and cleaning of the coal at the preparation plant, and are on a run-of-mine basis. The actual mining costs will vary from one mine to another, often due to local mining conditions of roof, bed thickness, depth from the surface, and other conditions of nature.

Costs given in these case studies do not include sales and general administration costs. They do not include transportation costs to point of use.

Detailed estimated costs for Mine "A" follow:

4.2 MINE "A"

Illinois No. 6 Bed - Franklin County

Deep Mine Coal - Crushed to 3 1/2" x 0

See Flow Sheet Figure No. 23

Estimated Costs per Ton of Product (f.o.b. Mine)

Preparation Plant Capital Cost = $2,560,000
for 700 t.p.h. raw coal feed capacity

I. If coal is washed at 1.60 separating density = 90.0 % yield (@ 99 % efficiency)

(a) Operating Costs (plant)

Labor	$0.102/ton product
Maintenance	0.079
Supplies	0.105
Power	0.058
Refuse handling	0.025
Total operating	$0.369/ton product

(b) Depreciation at 20 years straight line

@ 1,800,000 tons per year = $0.071

(c) Mining Costs

Run of Mine	$2.75/ton
@ 90 % yield	3.055

(d) Total costs f.o.b. mine, washed at 1.60 separating density

Plant Operating	$0.369
Depreciation	0.071
Mining	3.055
Total	$3.495/ton product

(e) Total cost per million Btu @ 11,900 Btu/lb.,f.o.b.= 14.6 cents

II. If coal is washed at 1.45 separating density, yield = 84.0 % (@ 97 % efficiency)

Plant Operating	$0.392/ton product
Depreciation	0.076
Mining	3.250
Total cost f.o.b. -	$3.718/ton product

Total cost per million Btu @ 12,000 Btu/lb., f.o.b. = 15.5 cents

Mine "A" - Continued

III. If coal is washed at 1.35 separating density, yield = 68.5%
(@ 95 % efficiency)

Plant Operating	$0.471
Depreciation	0.090
Mining	3.891
Total cost f.o.b.	$4.452/ton product

Total cost per million Btu @ 12,200 Btu/lb., f.o.b. = 18.4 cents

IV. Total Sulfur - Clean Coal

@ 1.35 Specific Gravity	=	2.20 %
1.45 " "	=	2.32
1.60 " "	=	2.43
Raw coal sulfur content	=	2.93

"Efficiency" is the measure of performance of this plant in terms of recovery or yield to meet the theoretical ash and sulfur shown in the float and sink analyses. This plant as designed cannot separate at a 1.35 separating density.

Figure 18

Relation of Cost per Million Btu. to Sulfur Reduction

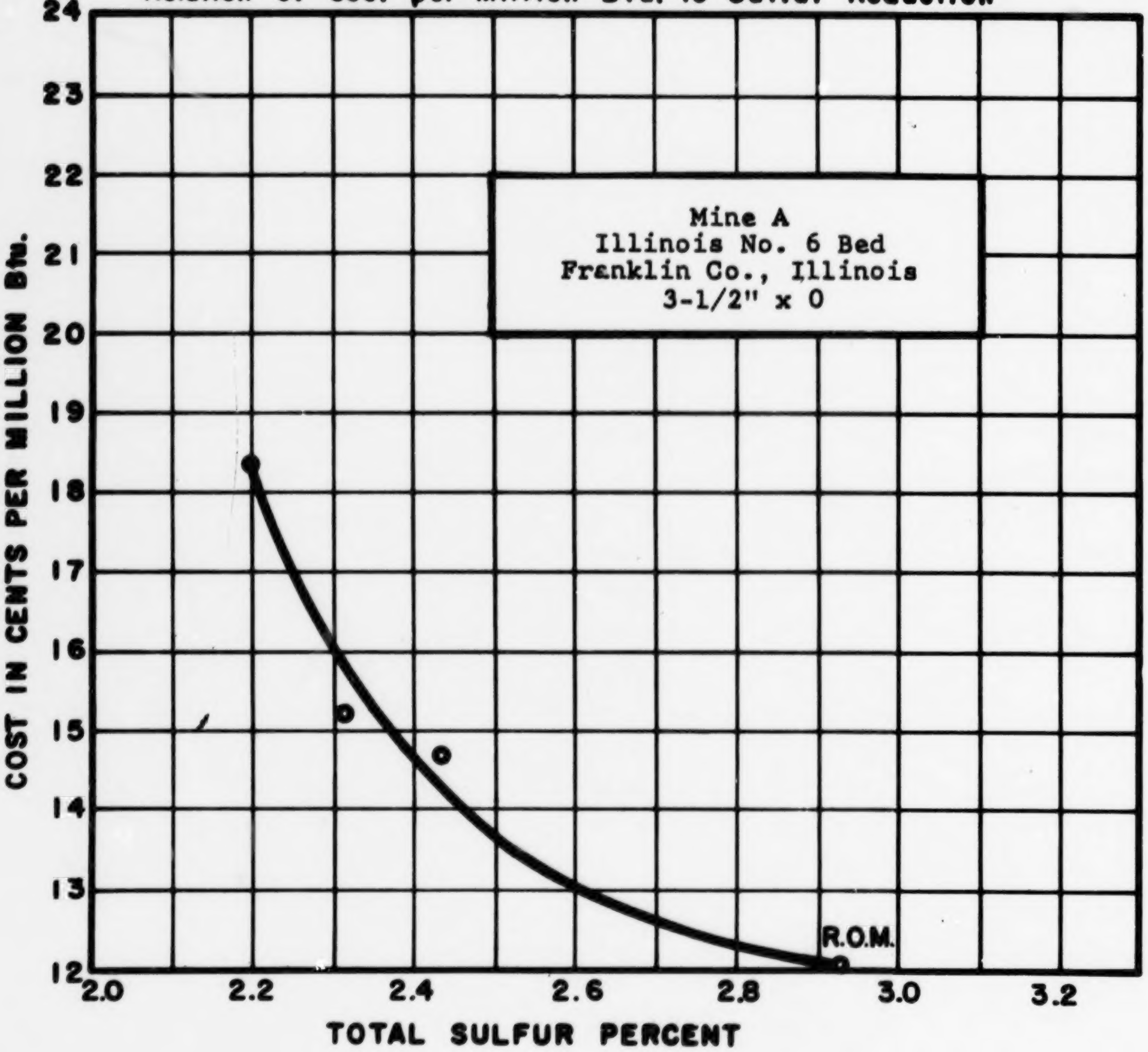


Table No. 10

MINE "A"

Illinois No. 6 Bed

Franklin County

Combined Washability Data 3-1/2" x 0 Composite

Specific Gravity		Weight %	Ash %	Sulphur %	Float Cumulative Weight %	Float Cumulative Ash %	Float Cumulative Sulphur %	Sink Cumulative Weight %	Sink Cumulative Ash %	Sink Cumulative Sulphur %
Float	1.30	44.58	4.37	2.13	44.58	4.37	2.13	100.00	11.67	2.93
1.30	1.35	27.66	7.50	2.31	72.24	5.57	2.20	55.42	17.53	3.58
1.35	1.40	12.04	13.12	2.80	84.28	6.65	2.29	27.76	27.53	4.84
1.40	1.45	2.38	18.68	3.39	86.66	6.98	2.32	15.72	38.57	6.40
1.45	1.50	2.25	20.68	4.00	88.91	7.32	2.36	13.34	42.11	6.93
1.50	1.60	2.19	26.60	5.54	91.10	7.79	2.43	11.09	46.46	7.53
1.60	Sink	8.90	51.35	8.02	100.00	11.67	2.93	8.90	51.35	8.02

Table No. 11

MINE "A"

Illinois No. 6 Bed

Franklin County

Washability Analysis 3-1/2" x 1" Size Fraction from ROM Sample

Specific Gravity		Weight %	Ash %	Sulphur %	Float Cumulative Weight %	Float Cumulative Ash %	Float Cumulative Sulphur %	Sink Cumulative Weight %	Sink Cumulative Ash %	Sink Cumulative Sulphur %
Float	1.30	23.09	3.83	2.06	23.09	3.83	2.06	100.00	12.55	3.15
1.30	1.35	38.84	7.21	2.28	61.93	5.95	2.20	76.91	15.16	3.47
1.35	1.40	18.08	13.38	2.86	80.01	7.63	2.35	38.07	23.28	4.69
1.40	1.45	3.03	18.26	3.34	83.04	8.02	2.38	19.99	32.23	6.34
1.45	1.50	3.26	19.28	4.10	86.30	8.44	2.45	16.96	34.73	6.88
1.50	1.60	3.25	24.76	6.06	89.55	9.03	2.58	13.70	38.41	7.54
1.60	Sink	10.45	42.65	8.00	100.00	12.55	3.15	10.45	42.65	8.00

Table No. 12

MINE "A"

Illinois No. 6 Bed

Franklin County

Washability Analysis 1" x 1/4" Size Fraction From ROM Sample

Specific Gravity		Weight %	Ash %	Sulphur %	Float Cumulative			Sink Cumulative		
					Weight %	Ash %	Sulphur %	Weight %	Ash %	Sulphur %
Float	1.30	38.01	3.45	2.14	38.01	3.45	2.14	100.00	10.95	3.13
1.30	1.35	37.20	7.15	2.32	75.21	5.28	2.23	61.99	15.55	3.74
1.35	1.40	10.94	13.33	2.88	86.15	6.30	2.31	24.79	28.16	5.86
1.40	1.45	2.98	18.00	3.36	89.13	6.69	2.35	13.85	39.88	8.22
1.45	1.50	1.72	21.74	4.36	90.85	6.98	2.38	10.87	45.87	9.55
1.50	1.60	1.66	27.45	5.08	92.51	7.35	2.43	9.15	50.41	10.53
1.60	Sink	7.49	55.50	11.74	100.00	10.95	3.13	7.49	55.50	11.74

Table No. 13

MINE "A"

Illinois No. 6 Bed

Franklin County

Washability Analysis 1/4" x 0 Size Fraction from ROM Sample

Specific Gravity					Float Cumulative			Sink Cumulative		
		Weight %	Ash %	Sulphur %	Weight %	Ash %	Sulphur %	Weight %	Ash %	Sulphur %
Float	1.30	82.60	4.90	2.16	82.60	4.90	2.16	100.00	10.92	2.50
1.30	1.35	4.40	13.47	2.74	87.00	5.33	2.19	17.40	39.48	4.14
1.35	1.40	2.33	17.22	3.46	89.33	5.64	2.22	13.00	48.28	4.61
1.40	1.45	1.02	21.74	3.60	90.35	5.83	2.24	10.67	55.07	4.87
1.45	1.50	1.11	26.06	3.24	91.46	6.07	2.25	9.65	58.59	5.00
1.50	1.60	.99	34.34	3.46	92.45	6.37	2.26	8.54	62.82	5.23
1.60	Sink	7.55	66.55	5.46	100.00	10.92	2.50	7.55	66.55	5.46

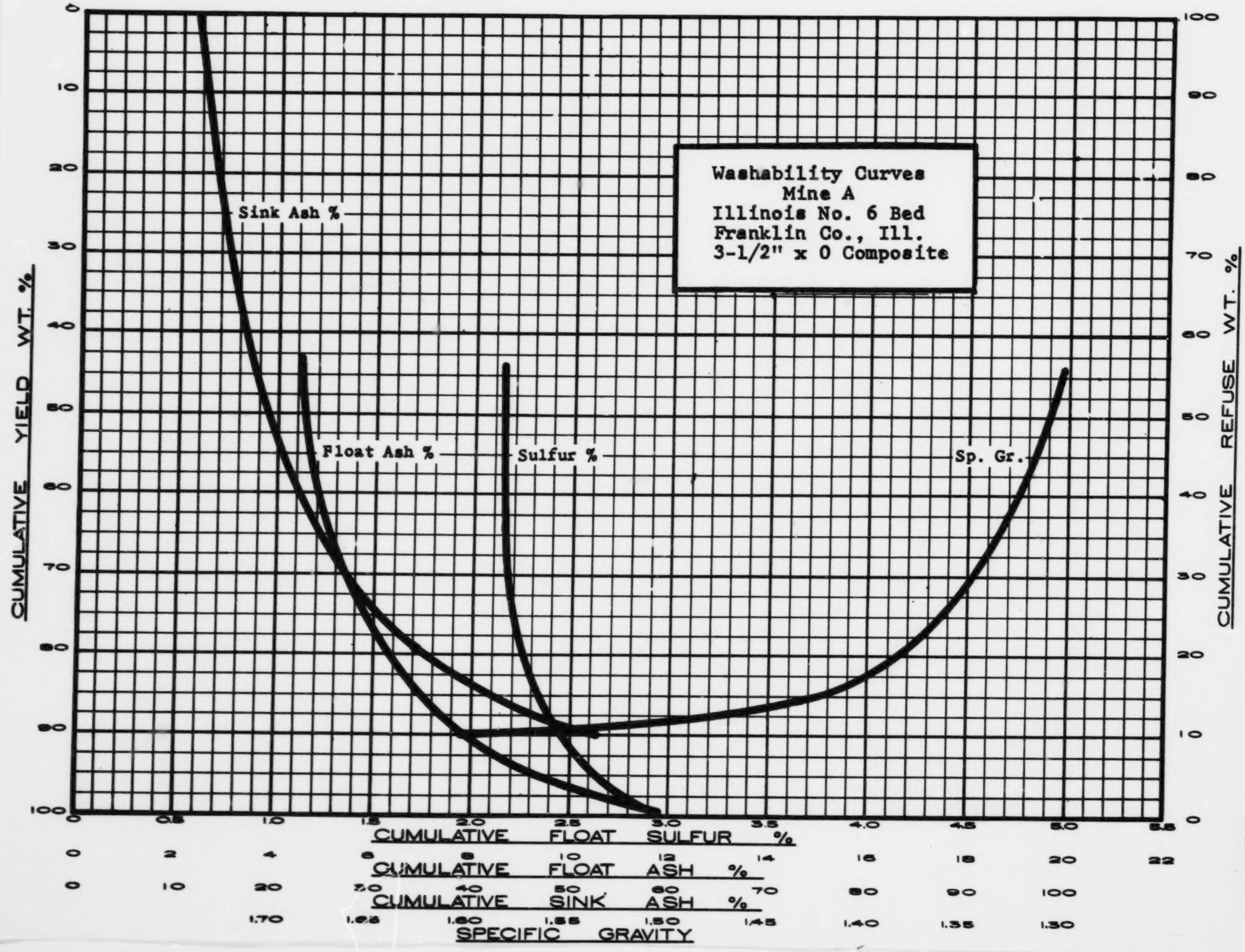
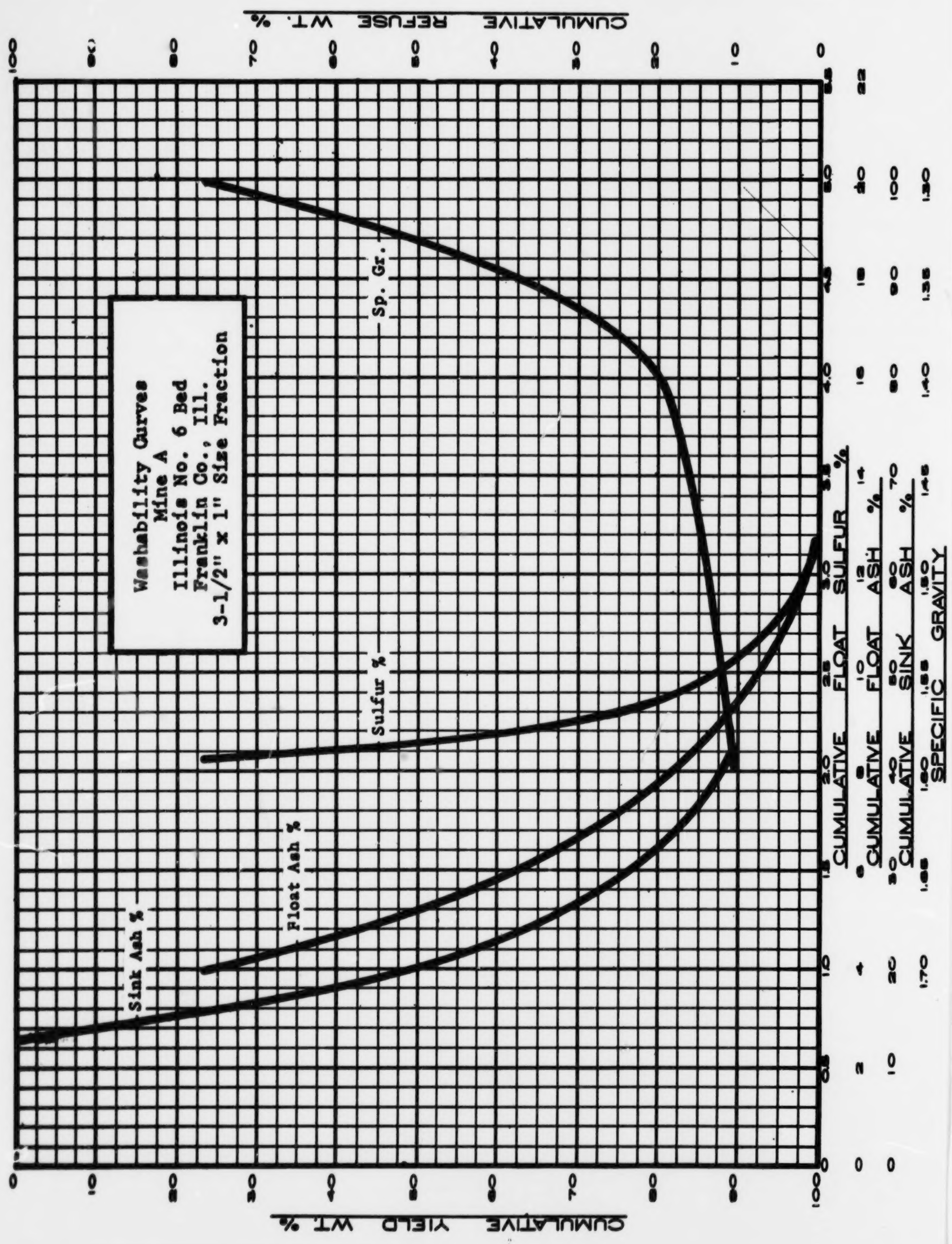

Washability Curves
Mine A
Illinois No. 6 Bed
Franklin Co., Ill.
3-1/2" x 0 Composite
Sink Ash %
Float Ash %
Sulfur %
Sp. Gr.
CUMULATIVE YIELD WT. %
0
10
20
30
40
50
60
70
80
90
100
CUMULATIVE REFUSE WT. %
100
90
80
70
60
50
40
30
20
10
0
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
CUMULATIVE FLOAT SULFUR %
0
2
4
6
8
10
12
14
16
18
20
22
CUMULATIVE FLOAT ASH %
0
10
20
30
40
50
60
70
80
90
100
CUMULATIVE SINK ASH %
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30
SPECIFIC GRAVITY

Figure 19

Figure 20


Washability Curves
Mine A
Illinois No. 6 Bed
Franklin Co., Ill.
3-1/2" x 1" Size Fraction
Sp. Gr.
Sulfur %
Float Ash %
Sink Ash %
CUMULATIVE YIELD WT. %
0
10
20
30
40
50
60
70
80
90
100
CUMULATIVE REFUSE WT. %
100
90
80
70
60
50
40
30
20
10
0
CUMULATIVE FLOAT SULFUR %
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
CUMULATIVE FLOAT ASH %
0
2
4
6
8
10
12
14
16
18
20
22
CUMULATIVE SINK ASH %
0
10
20
30
40
50
60
70
80
90
100
SPECIFIC GRAVITY
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30

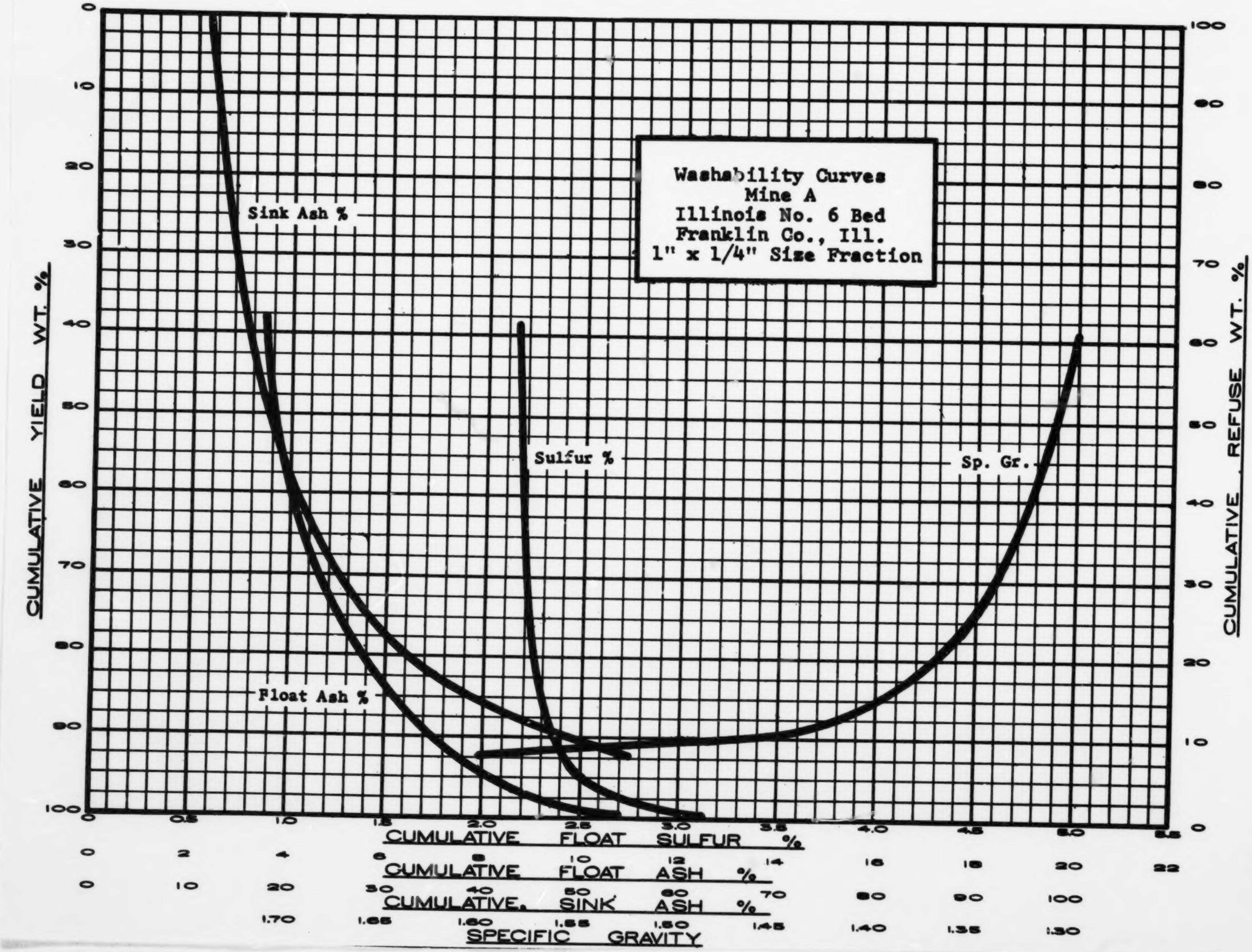
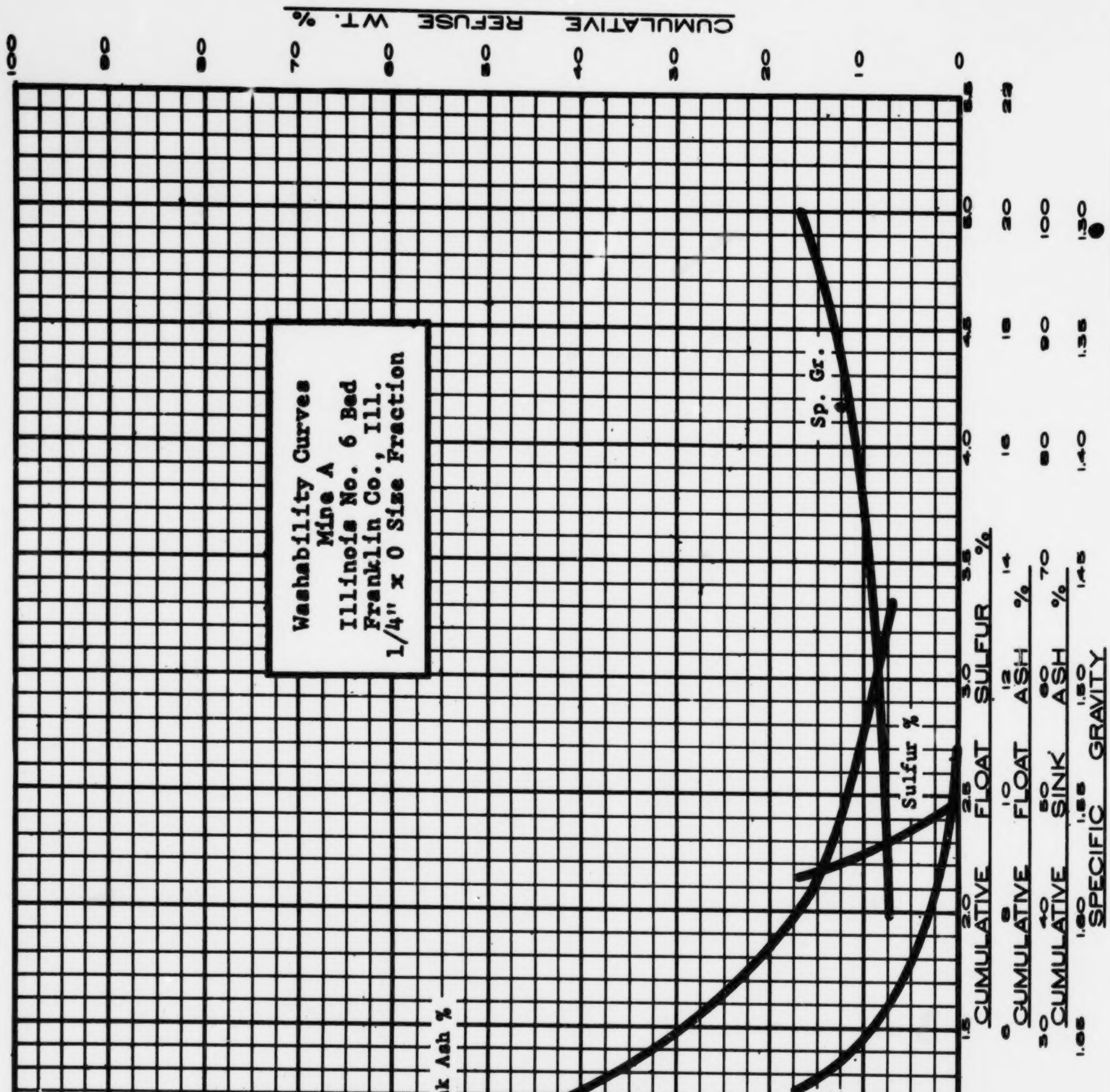

Washability Curves
Mine A
Illinois No. 6 Bed
Franklin Co., Ill.
1" x 1/4" Size Fraction
Sink Ash %
Sulfur %
Sp. Gr.
Float Ash %
CUMULATIVE YIELD WT. %
0
10
20
30
40
50
60
70
80
90
100
CUMULATIVE REFUSE WT. %
100
90
80
70
60
50
40
30
20
10
0
CUMULATIVE FLOAT SULFUR %
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
CUMULATIVE FLOAT ASH %
0
2
4
6
8
10
12
14
16
18
20
22
CUMULATIVE, SINK ASH %
0
10
20
30
40
50
60
70
80
90
100
SPECIFIC GRAVITY
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30

Figure 21

Figure 22


Washability Curves
Mine A
Illinois No. 6 Bed
Franklin Co., Ill.
1/4" x 0 Size Fraction
Sp. Gr.
Sulfur %
Sink Ash %
Float Ash %
CUMULATIVE REFUSE WT. %
0 10 20 30 40 50 60 70 80 90 100
CUMULATIVE YIELD WT. %
0 10 20 30 40 50 60 70 80 90 100
CUMULATIVE FLOAT SULFUR %
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5
CUMULATIVE FLOAT ASH %
0 2 4 6 8 10 12 14 16 18 20 22
CUMULATIVE SINK ASH %
0 10 20 30 40 50 60 70 80 90 100
SPECIFIC GRAVITY
1.70 1.65 1.60 1.55 1.50 1.45 1.40 1.35 1.30

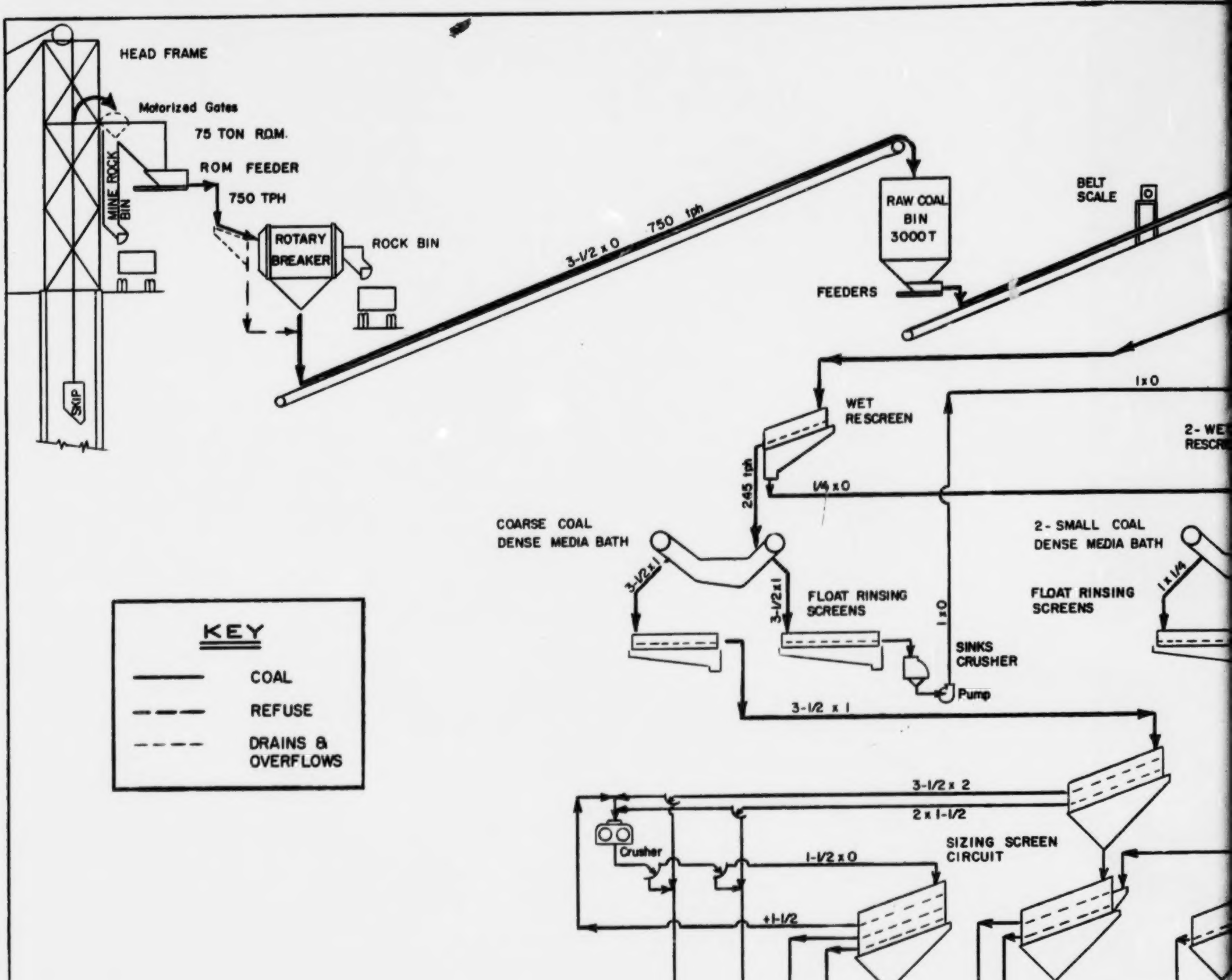
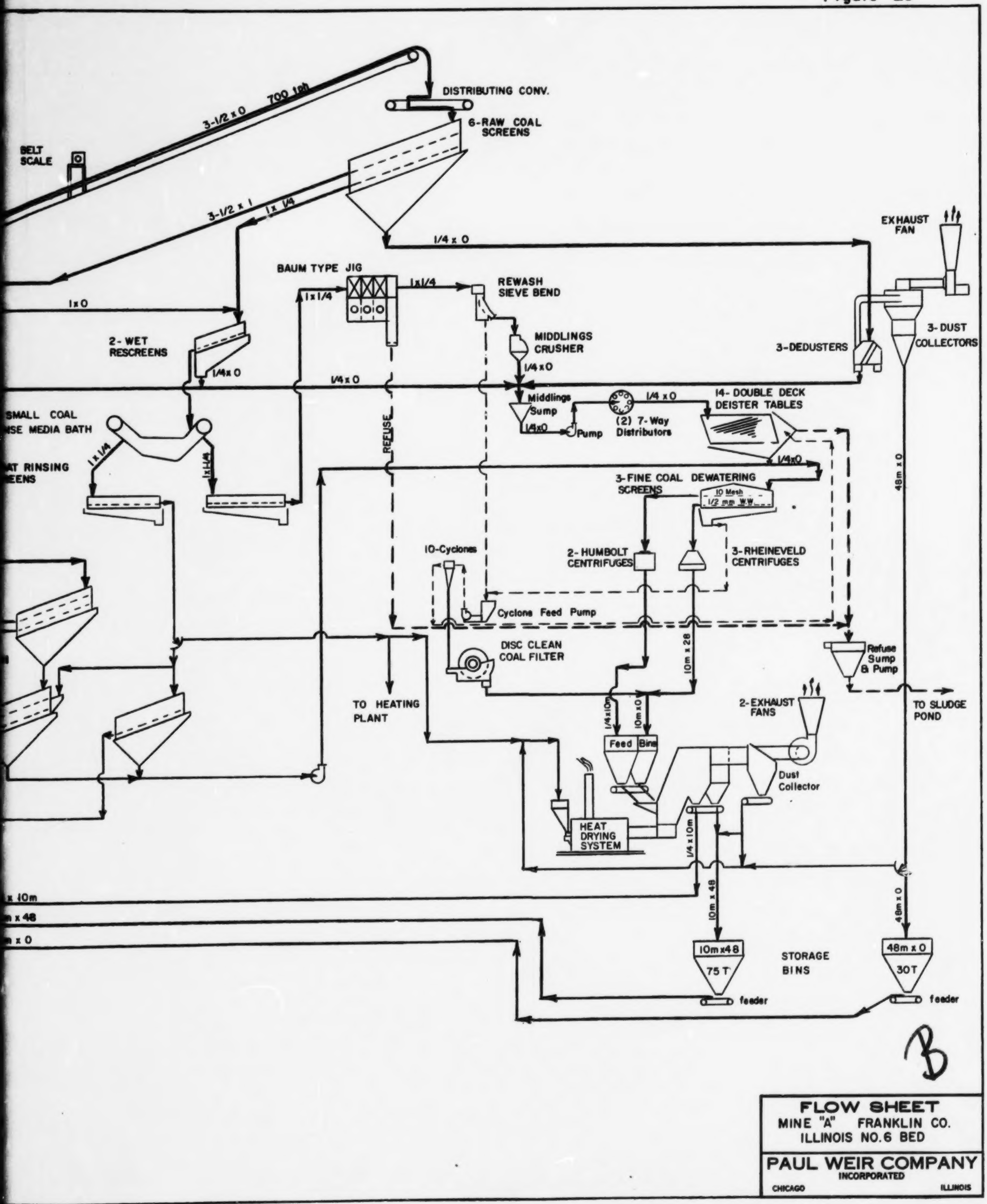

HEAD FRAME
Motorized Gates
75 TON ROM.
ROM FEEDER
750 TPH
MINE ROCK BIN
SKIP
ROTARY BREAKER
ROCK BIN
3-1/2 x 0 750 tph
RAW COAL BIN 3000T
FEEDERS
BELT SCALE
1x0
WET RESCREEN
2- WE
RESCR
245 tph
1/4 x 0
COARSE COAL DENSE MEDIA BATH
3-1/2 x 1
3-1/2 x 1
FLOAT RINSING SCREENS
1x0
SINKS CRUSHER
Pump
2- SMALL COAL DENSE MEDIA BATH
FLOAT RINSING SCREENS
1 x 1/4
KEY
COAL
REFUSE
DRAINS & OVERFLOWS
3-1/2 x 1
3-1/2 x 2
2 x 1-1/2
Crusher
1-1/2 x 0
SIZING SCREEN CIRCUIT
+1-1/2
1/4 x 10m
10m x 48
48m x 0
3-1/2 x 2
2 x 1-1/2
1-1/2 x 1
1 x 1/4
1/4 x 0
5- LOADING BELTS 650tph CAPACITY EA.
5- MOTORIZED TWO - WAY LOADING CHUTES
A

Figure 23


DISTRIBUTING CONV.
3-1/2 x 0
700 tph
6-RAW COAL SCREENS
BELT SCALE
3-1/2 x 1
1 x 1/4
1/4 x 0
EXHAUST FAN
BAUM TYPE JIG
1 x 1/4
REWASH SIEVE BEND
1 x 0
1 x 1/4
2- WET RESCREENS
MIDDLINGS CRUSHER
3-DUST COLLECTORS
3-DEDUSTERS
1/4 x 0
1/4 x 0
1/4 x 0
Middlings Sump
1/4 x 0
Pump
1/4 x 0
(2) 7-Way Distributors
14- DOUBLE DECK DEISTER TABLES
SMALL COAL
NSE MEDIA BATH
REFUSE
1 x 1/4
1 x 1/4
AT RINSING
EENS
1/4 x 0
48m x 0
3-FINE COAL DEWATERING SCREENS
10 Mesh
1/2 mm W.W.
10-Cyclones
2- HUMBOLT CENTRIFUGES
3- RHEINEVELD CENTRIFUGES
Cyclone Feed Pump
DISC CLEAN COAL FILTER
10m x 28
Refuse Sump & Pump
TO SLUDGE POND
TO HEATING PLANT
2-EXHAUST FANS
1/4 x 10m
10m x 0
Feed Bins
Dust Collector
HEAT DRYING SYSTEM
1/4 x 10m
x 10m
m x 48
m x 0
10m x 48
48m x 0
10m x 48
75 T
STORAGE BINS
48m x 0
30 T
feeder
feeder

B

FLOW SHEET
MINE "A" FRANKLIN CO.
ILLINOIS NO. 6 BED

PAUL WEIR COMPANY
INCORPORATED
CHICAGO ILLINOIS

4.3 Case Study, Mine "B"

Mine "B" is likewise an underground mine producing coal from the Illinois No. 6 bed. This mine, however, is in Montgomery County or the mid-central or Springfield area rather than in Southern Illinois, the location of Mine "A".

This is an older plant, using a combination of wet washing and air tables for cleaning. It is not as efficient as the Mine "A" plant, but has a lower operating cost. It has a complex sizing and loading out arrangement which is not being installed in most plants today. Its capacity is 800 t.p.h. of run-of-mine.

Due to the type of equipment in this plant, it is not capable of cleaning coal at densities lower than 1.60, so the results shown for 1.45 and 1.35 are only theoretical.

As a result of lower Btu values, somewhat higher mining costs and poorer efficiency, it produces coal for about 17.7 cents per million Btu at 1.60 specific gravity. This plant, however, is closer to the consuming area and delivered costs are undoubtedly competitive.

Raw coal sulfur is 4.78 percent, with 1.60 separation reducing the coal to 3.93 percent. Organic sulfur is 2.00 percent. The processes used in this plant are not adaptable for reducing sulfur effectively.

Figure No. 24 gives the cost per million Btu as effected by sulfur reduction. Table No. 14 gives the float and sink data, Figure No. 25 presents the washability curves for this coal, and Figure No. 26 represents the flow sheet for this plant.

Estimated costs for Mine "B" follow:

4.3 MINE "B"

Illinois No. 6 Bed - Montgomery County

Deep Mine Coal - Crushed to 1 1/2" x 0

See Flow Sheet Figure No. 26

Estimated Costs per Ton of Product (f.o.b. Mine)

Preparation plant Capital cost = $2,200,000 for 800 t.p.h. raw coal feed capacity.

I. If coal is washed at 1.60 separating density = 81.5 % yield (@ 97 % efficiency)

(a) Operating Costs (plant)

Labor	$0.112/ton product
Maintenance	0.074
Supplies	0.066
Power	0.048
Refuse handling	0.032
Total operating	$0.332/ton product

(b) Depreciation at 20 years Straight line

@ 2,000,000 tons per year = $0.055/ton product

(c) Mining Costs

Run of Mine	$3.00/ton
@ 81.5 % yield	3.68/ton product

(d) Total costs f.o.b. mine, washed at 1.60 separating density

Plant Operating	$0.332
Depreciation	0.055
Mining	3.680
Total	$4.067/ton product

(e) Total cost per million Btu @ 11,500 Btu/lb. = 17.7 cents

II. If coal is washed at 1.45 separating density = 75.0 % yield (@ 95 % efficiency)

Plant Operating	$0.361
Plant Depreciation	0.059
Mining	3.935
Total Cost f.o.b.	$4.355/ton product

Total cost per million Btu @ 11,600 Btu/lb., f.o.b. = 18.7 cents

Mine "B" - Continued

III. If coal is washed at 1.35 separating density = 59.0 % yield (@ 93.5 % efficiency)

Plant Operating		$0.426
Depreciation		0.071
Mining		4.747
	Total costs f.o.b.	$5.244/ton product

Total cost per million Btu @ 11,800 Btu/lb., f.o.b. = 22 cents

IV. Total Sulfur Content - Clean Coal

@ 1.35 Specific Gravity = 3.58 %
1.45 " " = 3.80
1.60 " " = 3.93

Raw Coal Sulfur Content = 4.78

"Efficiency" is the measure of performance of this plant in terms of recovery or yield to meet the theoretical ash and sulfur shown in float and sink analyses. It would be impossible for this plant to operate at either 1.35 or 1.45.

Figure 24

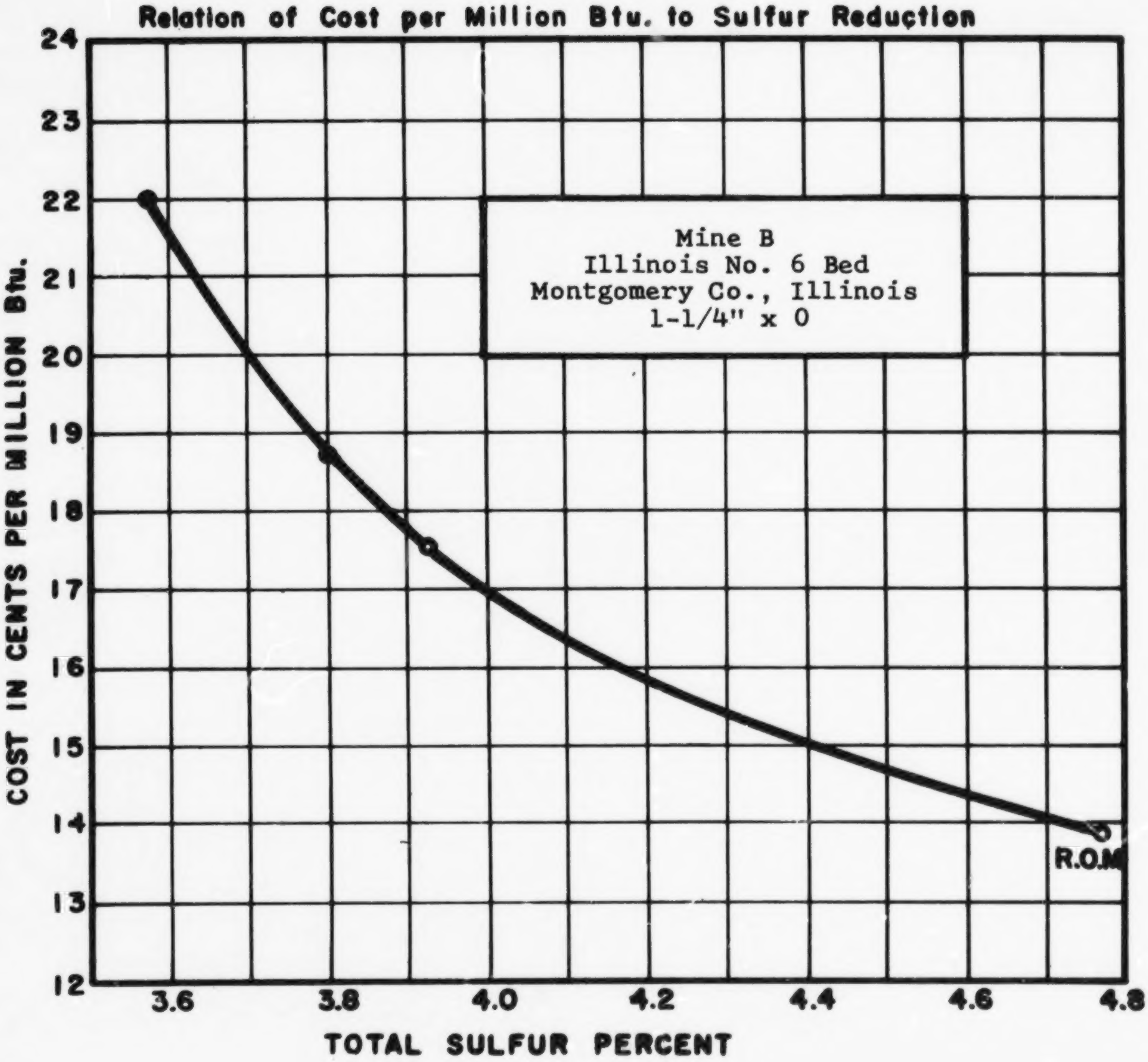

Relation of Cost per Million Btu. to Sulfur Reduction
COST IN CENTS PER MILLION Btu.
24
23
22
21
20
19
18
17
16
15
14
13
12
3.6
3.8
4.0
4.2
4.4
4.6
4.8
TOTAL SULFUR PERCENT
Mine B
Illinois No. 6 Bed
Montgomery Co., Illinois
1-1/4" x 0
R.O.M

Table No. 14

Table No. 14

MINE "B"

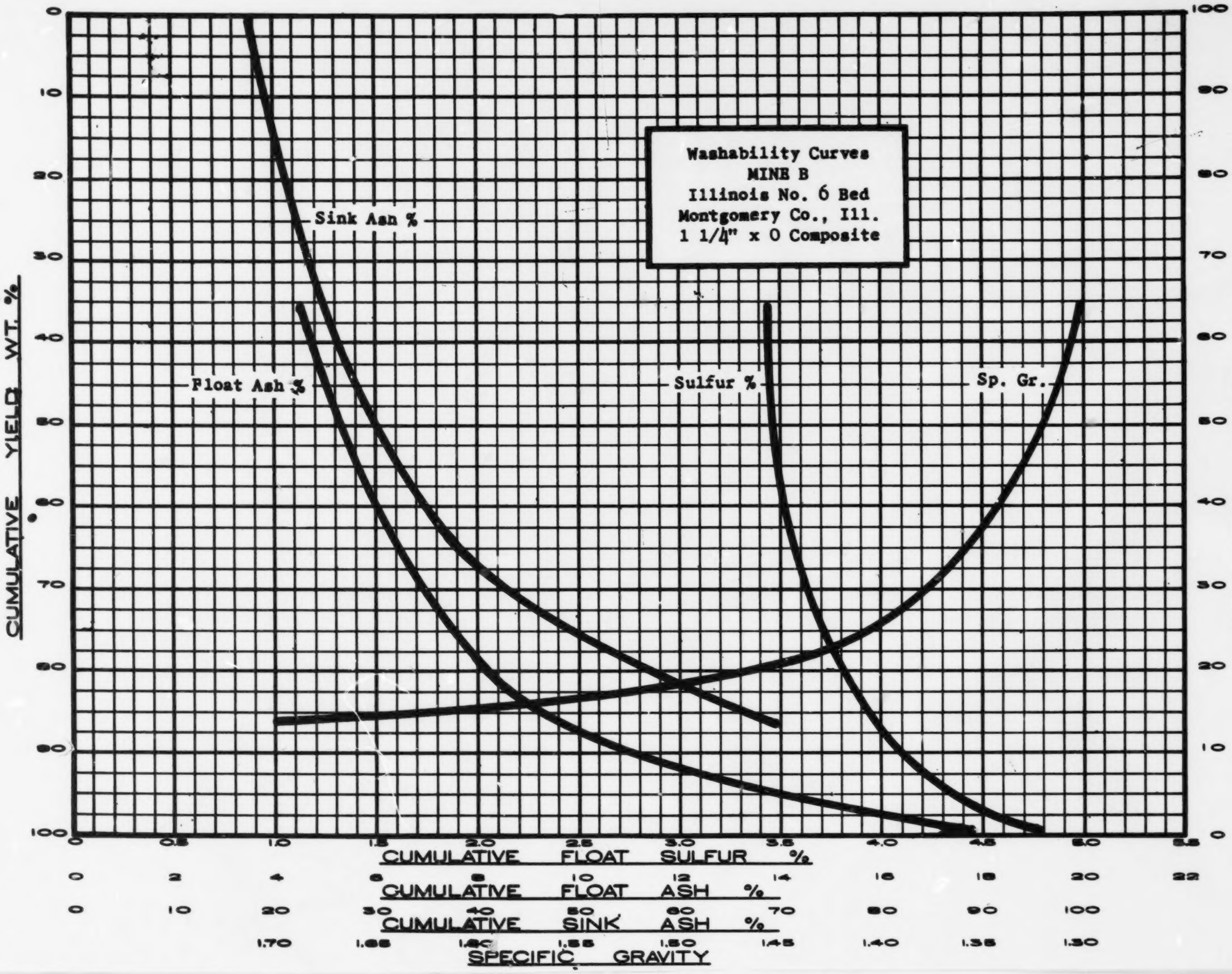
Illinois No. 6 Bed

Montgomery County

Combined Washability Data 1-1/4' x 0 Composite

Specific Gravity		Weight %	Ash %	Sulphur %	Float Cumulative			Sink Cumulative		
					Weight %	Ash %	Sulphur %	Weight %	Ash %	Sulphur %
Float	1.30	35.68	4.5	3.44	35.68	4.5	3.44	100.00	17.8	4.78
1.30	1.35	27.45	8.8	3.75	63.13	6.4	3.58	64.32	25.1	5.53
1.35	1.40	11.20	13.1	4.33	74.33	7.4	3.69	36.87	37.3	6.86
1.40	1.50	7.82	18.8	5.39	82.15	8.5	3.85	25.67	47.9	7.96
1.50	1.70	4.30	32.3	6.36	86.45	9.7	3.98	17.85	60.6	9.08
1.70	Sink	13.55	69.6	9.95	100.00	17.8	4.78	13.55	69.6	9.95

Figure 25


Washability Curves
MINE B
Illinois No. 6 Bed
Montgomery Co., Ill.
1 1/4" x 0 Composite
Sink Ash %
Float Ash %
Sulfur %
Sp. Gr.
CUMULATIVE YIELD WT. %
0
10
20
30
40
50
60
70
80
90
100
CUMULATIVE REFUSE WT. %
100
90
80
70
60
50
40
30
20
10
0
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5
CUMULATIVE FLOAT SULFUR %
0 2 4 6 8 10 12 14 16 18 20 22
CUMULATIVE FLOAT ASH %
0 10 20 30 40 50 60 70 80 90 100
CUMULATIVE SINK ASH %
1.70 1.65 1.60 1.55 1.50 1.45 1.40 1.35 1.30
SPECIFIC GRAVITY

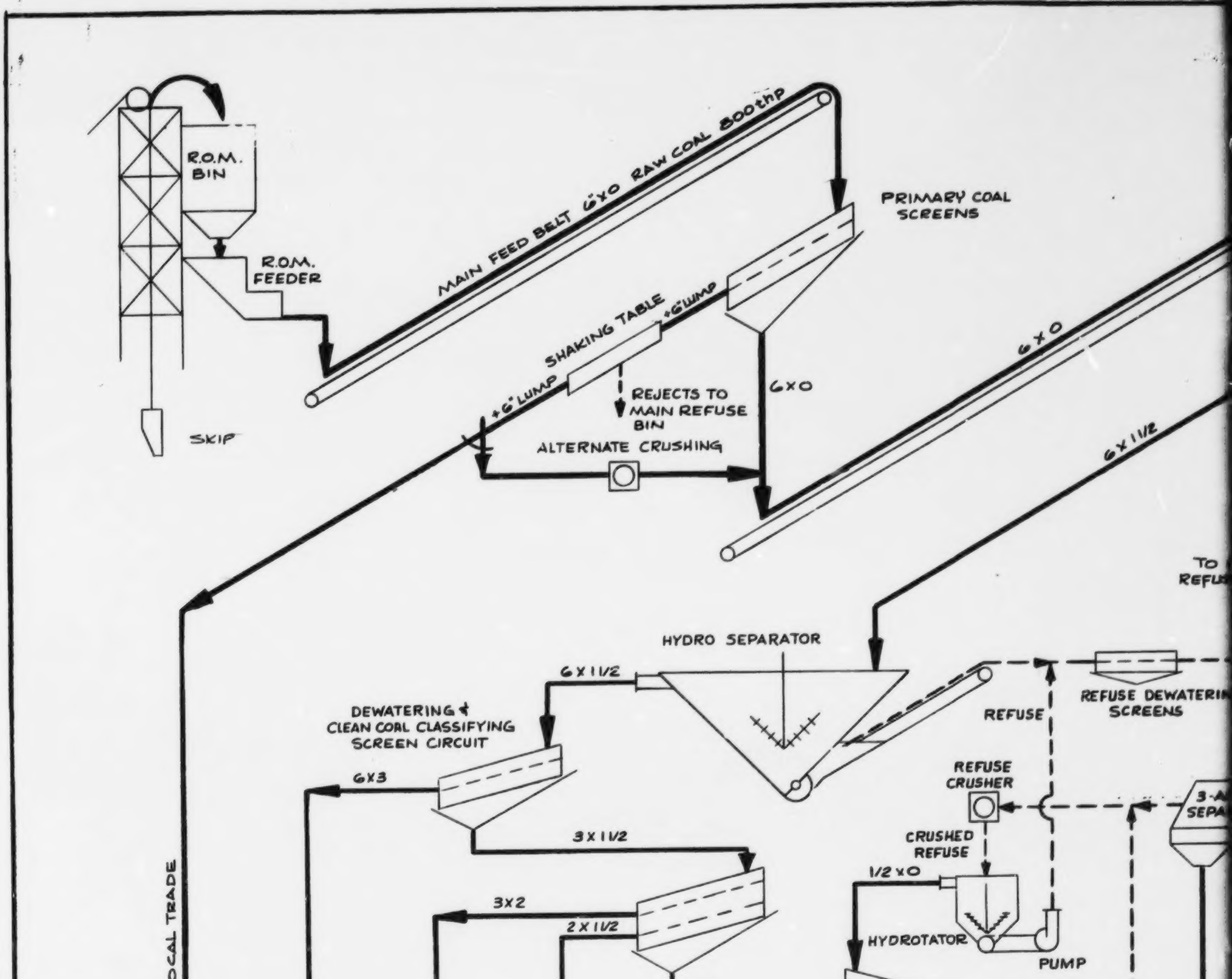
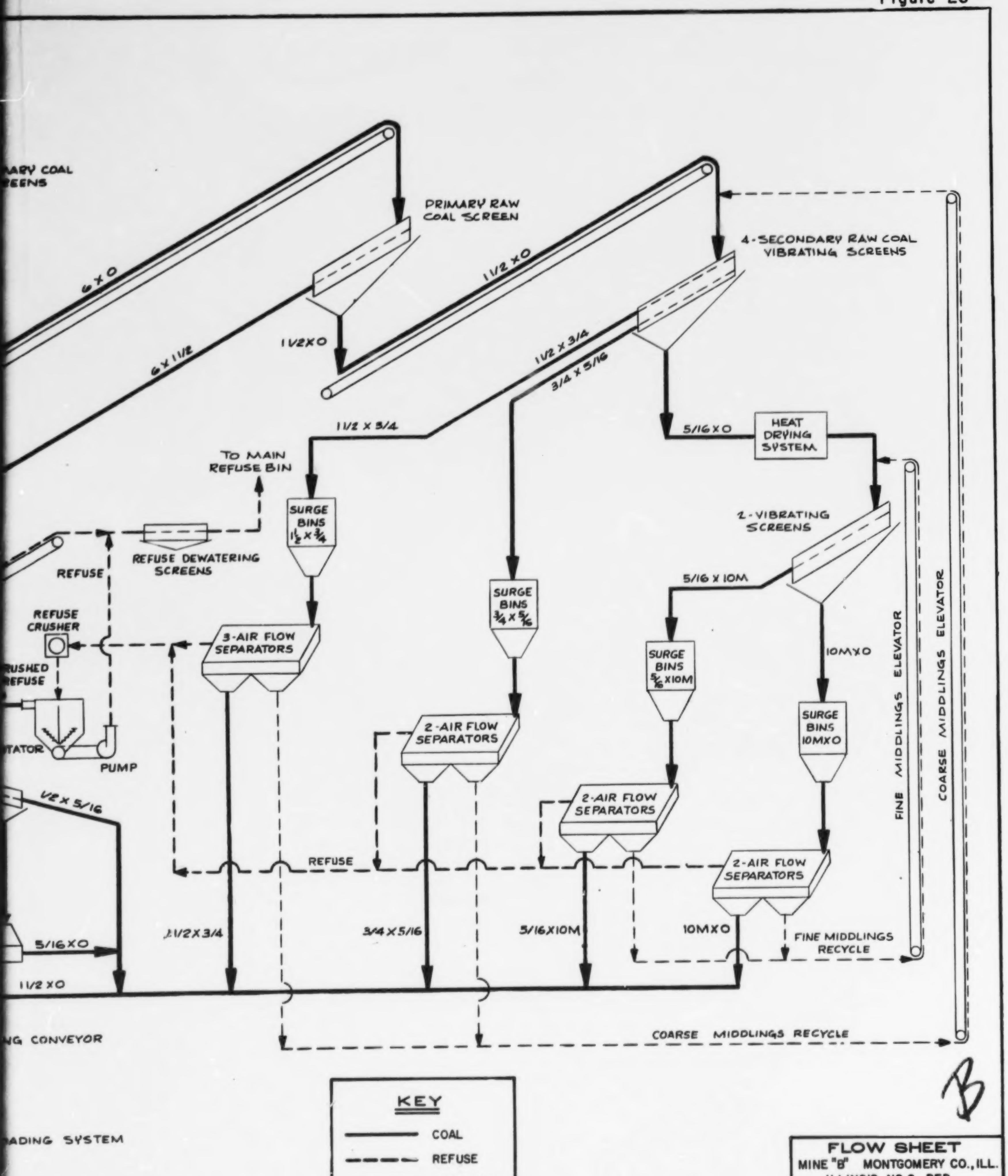

R.O.M. BIN
R.O.M. FEEDER
SKIP
MAIN FEED BELT 6"x0 RAW COAL 800tph
PRIMARY COAL SCREENS
SHAKING TABLE
+6" LUMP
+6" LUMP
REJECTS TO MAIN REFUSE BIN
6x0
ALTERNATE CRUSHING
6x0
6x11/2
TO REFU
HYDRO SEPARATOR
6x11/2
DEWATERING & CLEAN COAL CLASSIFYING SCREEN CIRCUIT
6x3
3x11/2
3x2
2x11/2
11/2x0
11/2x5/16
5/16x0
REFUSE
REFUSE DEWATERIN SCREENS
REFUSE CRUSHER
CRUSHED REFUSE
1/2x0
HYDROTATOR
PUMP
1/2x5/16
3-A SEPA
CENTRIFUGAL DRYERS
5/16x0
11/2x0
11/2x3/4
+6" LUMP RR LOADING & LOCAL TRADE
MIXING CONVEYOR
+6" LUMP
6x3
3x2
2x1½
1½x5/16
1½x0
RR LOADING SYSTEM
A

Figure 26



MARY COAL
EENS
PRIMARY RAW
COAL SCREEN
6 X 0
6 X 11/2
11/2 X 0
4-SECONDARY RAW COAL
VIBRATING SCREENS
11/2 X 0
11/2 X 3/4
3/4 X 5/16
5/16 X 0
HEAT
DRYING
SYSTEM
11/2 X 3/4
TO MAIN
REFUSE BIN
SURGE
BINS
11/2 X 3/4
REFUSE DEWATERING
SCREENS
REFUSE
REFUSE
CRUSHER
RUSHED
EFUSE
TATOR
PUMP
3-AIR FLOW
SEPARATORS
SURGE
BINS
3/4 X 5/16
2-VIBRATING
SCREENS
5/16 X 10M
10M X 0
SURGE
BINS
5/16 X 10M
SURGE
BINS
10M X 0
2-AIR FLOW
SEPARATORS
2-AIR FLOW
SEPARATORS
2-AIR FLOW
SEPARATORS
1/2 X 5/16
REFUSE
5/16 X 0
11/2 X 0
11/2 X 3/4
3/4 X 5/16
5/16 X 10M
10M X 0
FINE MIDDLINGS
RECYCLE
FINE MIDDLINGS ELEVATOR
COARSE MIDDLINGS ELEVATOR
NG CONVEYOR
COARSE MIDDLINGS RECYCLE
ADING SYSTEM
KEY
COAL
REFUSE
MIDDLINGS
FLOW SHEET
MINE "B" MONTGOMERY CO., ILL.
ILLINOIS NO.6 BED
PAUL WEIR COMPANY
INCORPORATED
CHICAGO
ILLINOIS

B

4.4 Case Study, Mine "C"

Mine "C" is an example of a plant washing strip mined coal in Fulton County in Northern Illinois. They are mining the Illinois No. 5 bed. This plant uses basically Baum jigs for cleaning the coal, using two jigs for the 6" x 0, one for 2" x 0, and a middling jig. The 1/4" x 0 is rewashed in a Rheolavour launder system. The 3/4" x 1/8" product is heat dried. Its capacity is 800 t.p.h. run-of-mine coal.

This plant has a complicated seven track loading system with ability to produce almost any size of coal required for commercial use, most of which is not required in modern day practice. Mining costs are estimated as $2.50/ton run-of-mine.

On an "as received" Btu value of 10,800, it is estimated that at a 1.60 specific gravity of separation, the cost per million Btu, f.o.b. is 15.1 cents.

This cost would be increased to 16.3 cents at 1.45 and 19.6 cents at 1.35 separating density. In actual practice, it would be impossible for this plant to operate effectively at 1.35; 1.45 would be very difficult.

The test data for this coal shows a head total sulfur of 5.49 percent. The 1.60 separation reduces it to 4.28, 1.45 to 4.03, and 1.35 to 3.62 percent. Organic sulfur runs 2.20 percent.

Figure No. 27 shows the sulfur reduction versus cost per million Btu. Table No. 15 presents float and sink data, Figure No. 28, washability curves and Figure No. 29, a flow sheet of the preparation plant.

Estimated costs for Mine "C" follow:

4.4 MINE "C"

Illinois No. 5 Bed - Fulton County

Strip Mine Coal - Crushed to 1 1/2" x 0

See Flow Sheet Figure No.29

Estimated Costs per Ton of Product (f.o.b. Mine)

Preparation plant Capital Cost = $2,700,000 for 800 t.p.h., raw coal feed capacity

I. If coal is washed at 1.60 separating density = 85.0 percent yield (@ 98 % efficiency)

(a) Operating Costs (plant)

Labor	$0.070
Maintenance	0.060
Supplies	0.070
Power	0.035
Refuse handling	0.025
Total Operating	$0.260

(b) Depreciation at 20 years straight line

@ 2,000,000 tons per year - $ .068/ton product

(c) Mining Costs

Run of Mine	$2.50/ton
@ 85 % yield	2.94/ton product

(d) Total Costs f.o.b. mine, washed at 1.60 separating density

Plant Operating	$0.260
Depreciation	0.068
Mining	2.940
Total	$3.268/ton product

(e) Total Cost per million Btu @ 10,800 Btu/lb. = 15.1 cents f.o.b.

II. If coal is washed at 1.45 separating density = 76.5 % yield (@ 95 % efficiency)

Plant Operating	$0.285
Plant Depreciation	0.074
Mining	3.213
Total Costs f.o.b.	$3.572/ton product

Total costs per million Btu @ 10,900 Btu/lb. = 16.3 cents f.o.b.

Mine "C" Continued

III. If coal is washed @ 1.35 separating density = 60.0 % yield (@ 95% efficiency)

Plant Operating	$0.346
Plant Depreciation	0.090
Mining	3.920
Total Costs f.o.b.	$4.356/ton product

Total Costs per million Btu @ 11,100 Btu/lb. = 19.6 cents

IV. Total Sulfur - Clean Coal

@ 1.35 Specific Gravity	=	3.62 %
1.45 " "	=	4.03
1.60 " "	=	4.28
Raw coal sulfur content	=	5.49

"Efficiency" is the measure of performance of this plant in terms of recovery or yield to meet the theoretical ash and sulfur shown in float and sink analyses. It would be impossible for this plant to operate at 1.35.

Figure 27

Relation of Cost per Million Btu. to Sulfur Reduction

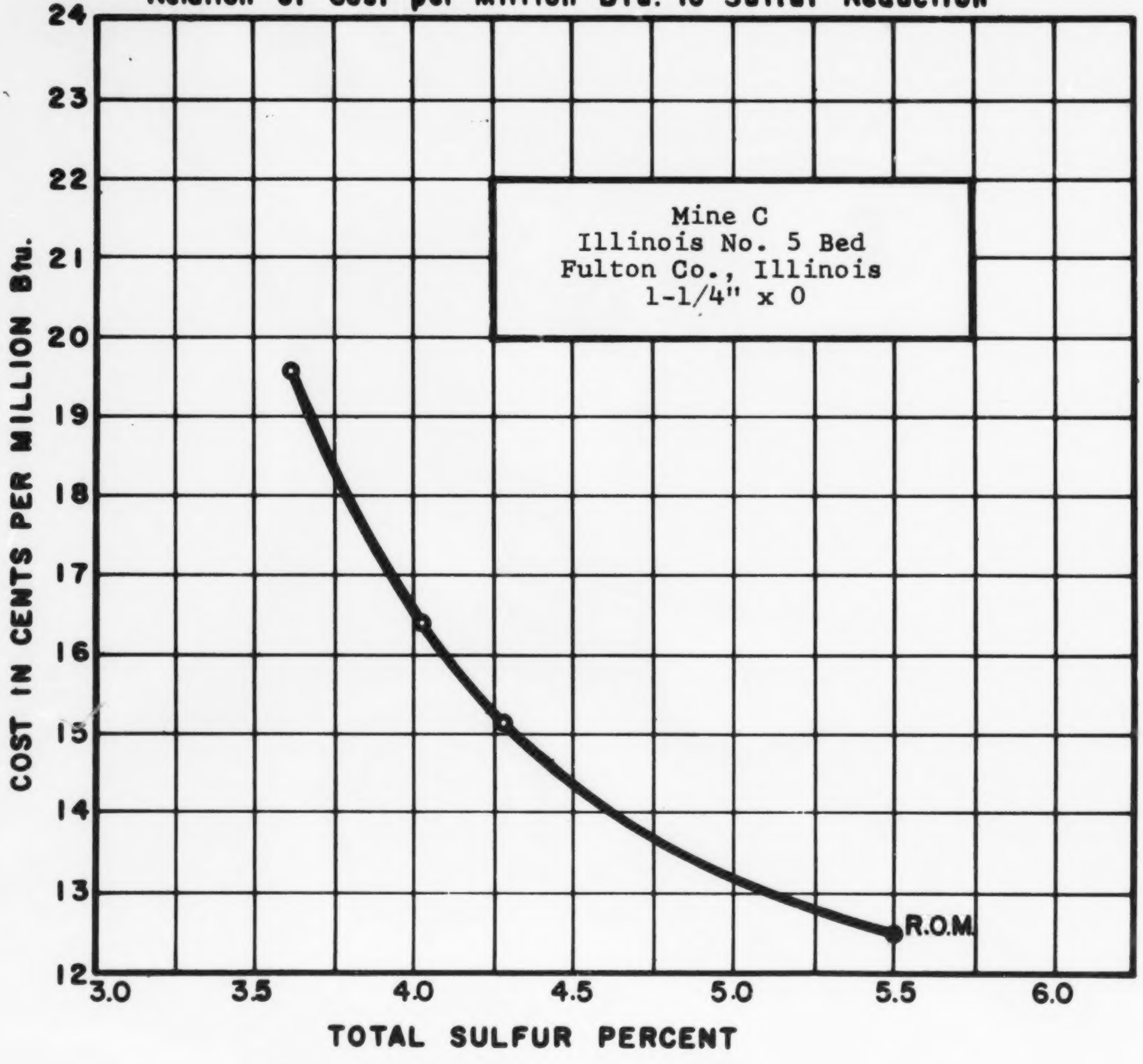


Table No. 15

MINE "C"

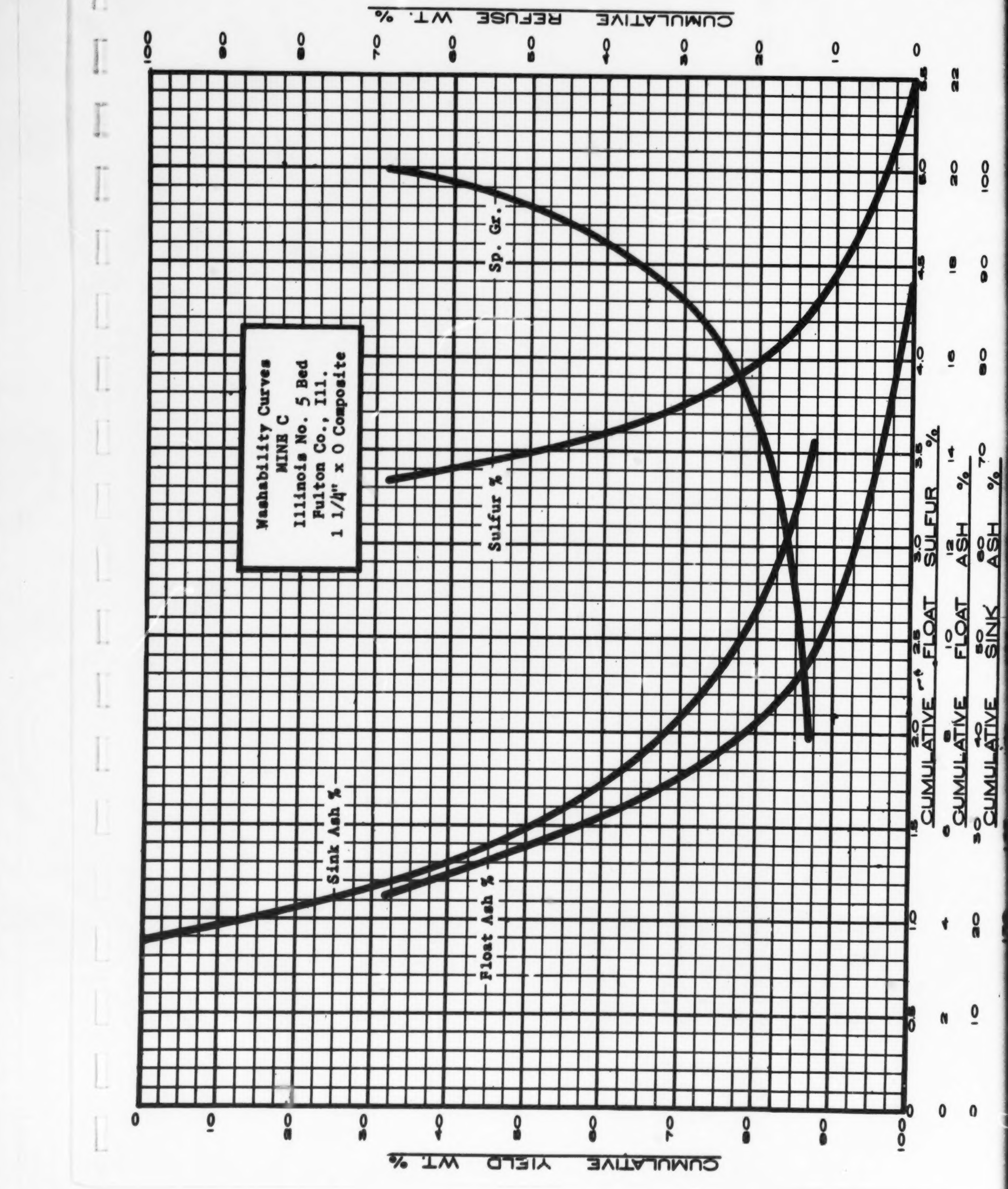
Illinois No. 5 Bed

Fulton County

Combined Washability Data 1 1/4" x 0 Composite

Specific Gravity		Direct			Float Cumulative			Sink Cumulative		
		Weight %	Ash %	Sulphur %	Weight %	Ash %	Sulphur %	Weight %	Ash %	Sulphur %
Float	1.30	30.84	4.53	3.32	30.84	4.53	3.32	100.00	17.59	5.49
1.30	1.35	32.43	8.66	3.91	63.27	6.65	3.62	69.16	23.42	6.46
1.35	1.40	13.43	13.49	5.11	76.70	7.85	3.88	36.73	36.45	8.70
1.40	1.45	3.86	19.53	6.85	80.56	8.40	4.03	23.30	49.68	10.77
1.45	1.50	3.87	19.53	6.85	84.43	8.91	4.15	19.44	55.67	11.55
1.50	1.55	1.23	28.82	8.49	85.66	9.20	4.22	15.57	64.65	12.72
1.55	1.60	1.24	28.82	8.48	86.90	9.48	4.28	14.34	67.73	13.08
1.60	Sink	13.10	71.41	13.52	100.00	17.49	5.49	13.60	71.41	13.52

Figure



Washability Curves
MINE C
Illinois No. 5 Bed
Fulton Co., Ill.
1 1/4" x 0 Composite

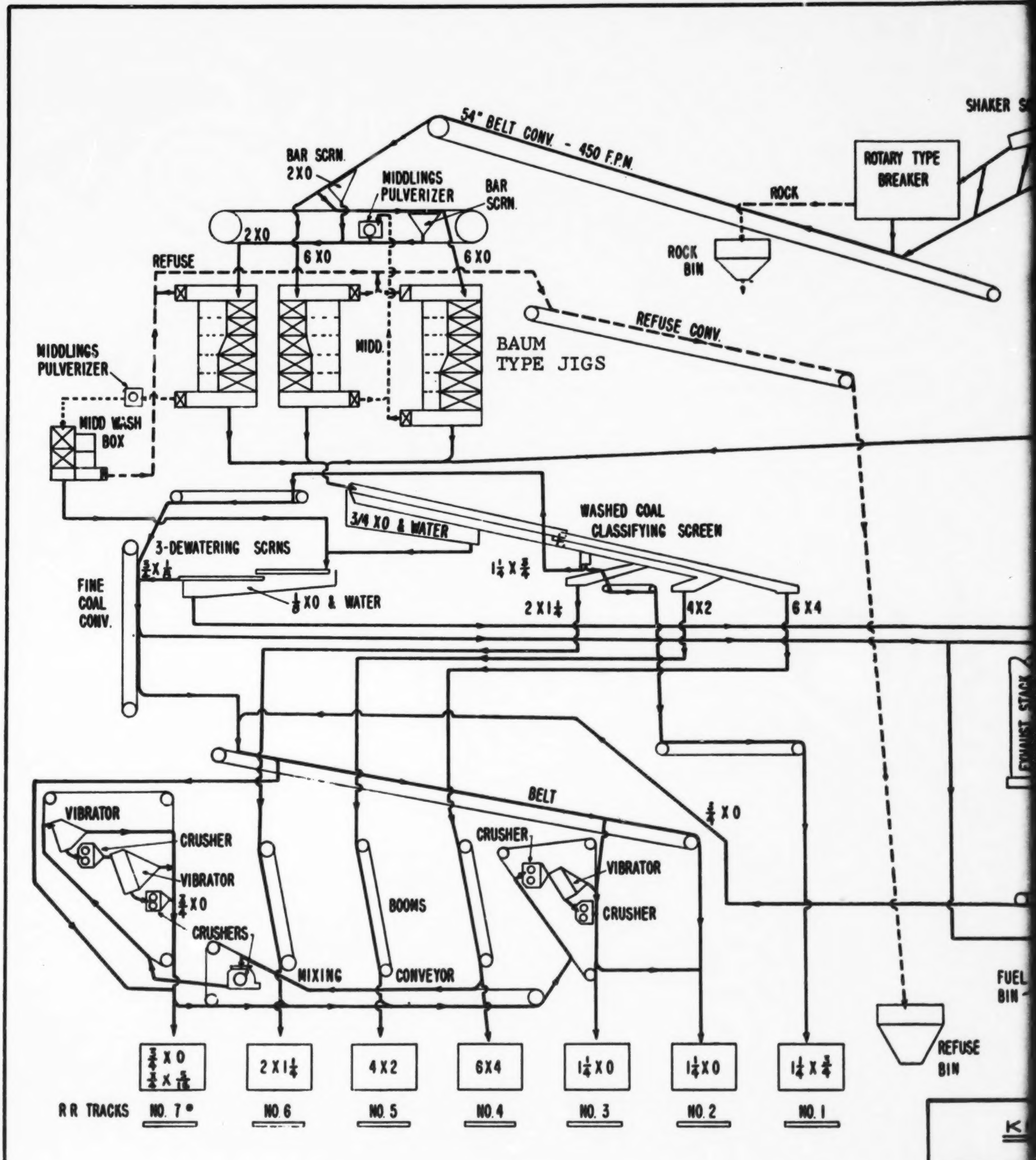
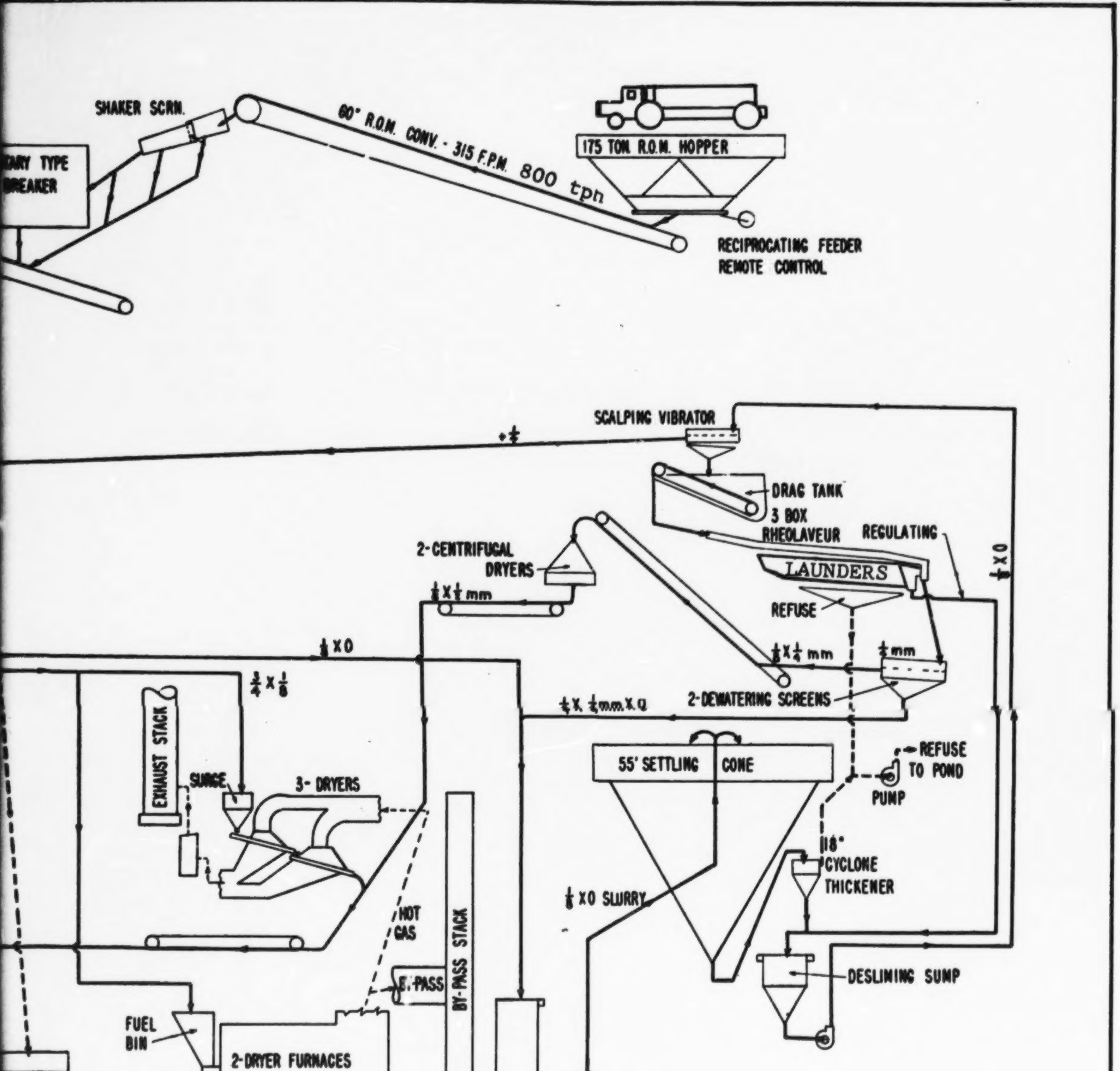

SHAKER S
54" BELT CONV. - 450 F.P.M.
ROTARY TYPE BREAKER
ROCK
ROCK BIN
BAR SCRN. 2X0
MIDDLINGS PULVERIZER
BAR SCRN.
2X0
6X0
6X0
REFUSE
REFUSE CONV.
BAUM TYPE JIGS
MIDD.
MIDDLINGS PULVERIZER
MIDD WASH BOX
3/4 XO & WATER
WASHED COAL CLASSIFYING SCREEN
3-DEWATERING SCRNS
3/4 X 1/8
1/8 XO & WATER
FINE COAL CONV.
1 1/4 X 3/4
2 X 1 1/4
4X2
6 X4
EXHAUST STACK
BELT
3/4 X 0
VIBRATOR
CRUSHER
VIBRATOR
3/4 X0
CRUSHERS
BOOMS
MIXING
CONVEYOR
CRUSHER
VIBRATOR
CRUSHER
FUEL BIN
REFUSE BIN
3/4 X 0
3/4 X 3/16
2 X 1 1/4
4 X 2
6X4
1 1/4 X 0
1 1/4 X 0
1 1/4 X 3/4
R R TRACKS
NO. 7 *
NO. 6
NO. 5
NO. 4
NO. 3
NO. 2
NO. 1
K
A

Figure 29


SHAKER SCRN.
60" R.O.M. CONV. - 315 F.P.M. 800 tph
175 TON R.O.M. HOPPER
ARY TYPE
REAKER
RECIPROCATING FEEDER
REMOTE CONTROL
SCALPING VIBRATOR
+1/4
DRAG TANK
3 BOX
RHEOLAVEUR
REGULATING
LAUNDERS
1/4 X 0
2-CENTRIFUGAL
DRYERS
1/8 X 1/4 mm
REFUSE
1/8 X 0
3/4 X 1/8
1/8 X 1/4 mm
1/4 mm
2-DEWATERING SCREENS
1/4 X 1/4 mm X 0
EXHAUST STACK
SURGE
3- DRYERS
55' SETTLING CONE
REFUSE
TO POND
PUMP
18" CYCLONE
THICKENER
1/8 X 0 SLURRY
HOT
GAS
BY-PASS STACK
B.-PASS
DESLIMING SUMP
FUEL
BIN
2-DRYER FURNACES
REFUSE
BIN
SLURRY
SUMP
KEY
COAL
REFUSE
MIDDLINGS
FLOW SHEET
MINE "C" - FULTON CO.
ILLINOIS NO. 5 BED
PAUL WEIR COMPANY
INCORPORATED
CHICAGO
ILLINOIS

B

4.5 Case Study, Mine "D"

Mine "D" is also in the midwest. This example is in West Kentucky and mines the No. 9 bed. It is a deep mine as distinct from a strip mine. The plant has a capacity of 1,000 t.p.h. of run-of-mine coal.

The basic cleaning process consists of two parallel Baum type jigs, and a smaller piston type jig for cleaning 28 mesh x 0. No heat dryers are used in this plant.

As a result of this simplified process, operating costs are low as well as capital investment. At a $2.85 mining cost R.O.M. and $0.241 per ton cleaning costs, the cost per million Btu, f.o.b. mine is 14.4 cents when separating at a 1.60 specific gravity. This increases to 16.1 cents at 1.45 and to as high as 19.0 cents at 1.35 due to loss of yield. This plant is not designed to separate at 1.45 or at 1.35.

The head total sulfur content is 4.07 percent. Separating at 1.60 reduces it to 3.15 percent; 1.45 to 2.72 percent and 1.35 to 2.44 percent. Organic sulfur in the No. 9 bed averages about 1.75 percent.

Figure No. 30 shows the sulfur reduction versus cost per million Btu. Table No. 16 gives the float and sink data, Figure No. 31, the washability curves, and Figure No. 32 shows the plant flow sheet.

As examples of washability for other seams in the West Kentucky coal field, Table No. 17 presents sulfur float and sink data for the No. 11 bed and Table No. 18 similar data for the No. 12 bed. Figure Nos. 33 and 34 show sulfur specific gravity curves for these two beds. Based upon these data, sulfur levels for these beds can be estimated.

Estimated costs for Mine "D" follow:

4.5 MINE "D"

West Kentucky #9 Bed - Union County

Deep Mine Operations - 5" x 0 Raw Coal
See Flow Sheet Figure No. 32

Estimated Costs per Ton of Product (f.o.b.) Mine

Preparation plant Capital Cost = $1,850,000. Capacity 1,000 t.p.h
(does not include overland belt conveyor system
which is not pertinent to plant operation)

1. If coal is washed at 1.60 separating density = 88 % yield (@ 98 % efficiency)

(a) Operating Costs (plant)

Labor	$0.040/ton product
Maintenance	0.035
Supplies	0.050
Power	0.030
Refuse handling	0.040
Total operating costs	$0.195/ton product

(b) Depreciation at 20 years straight line

@ 2,000,000 tons per year = $0.046

(c) Mining Costs --------------------- $2.850/ton run of Mine

@ 88 % yield ------------------- $3.238/ton of product

(d) Total Costs f.o.b. Mine, washing at 1.60 separating density

Plant operating	$0.195/ton product
Depreciation	0.046
Mining	3.238
Total Costs f.o.b.	$3.479/ton product

(e) Total costs per million Btu @ 12,600 Btu/lb. = 14.4 cents, f.o.b. mine

II. If coal is washed at 1.45 separating density = 72.0 % yield (@ 94 % efficiency)

Plant operating	$0.232/ton product
Plant depreciation	0.055
Mining	3.854
Total Costs f.o.b. -	$4.141/ton product

Total Costs f.o.b. = 16.1 cents per million Btu @ 12,800 Btu/lb.

Mine "D" - Continued

III. If coal is washed at 1.35 separating density = 58.4 % yield

Plant operating	$0.285/ton product
Plant Depreciation	0.067
Mining	4.600
Total Costs f.o.b. -	$4.952/ton product

Total Costs f.o.b. - 19.0 cents per million Btu
@ 13,000 Btu/lb.

IV. Total Sulfur - Clean Coal

@ 1.35 Specific Gravity = 2.44*
1.45 " " = 2.72*
1.60 " " = 3.15
Raw Coal Sulfur = 4.07

*Theoretical reductions. This plant cannot separate at 1.45 or 1.35 separating densities.

Figure 30

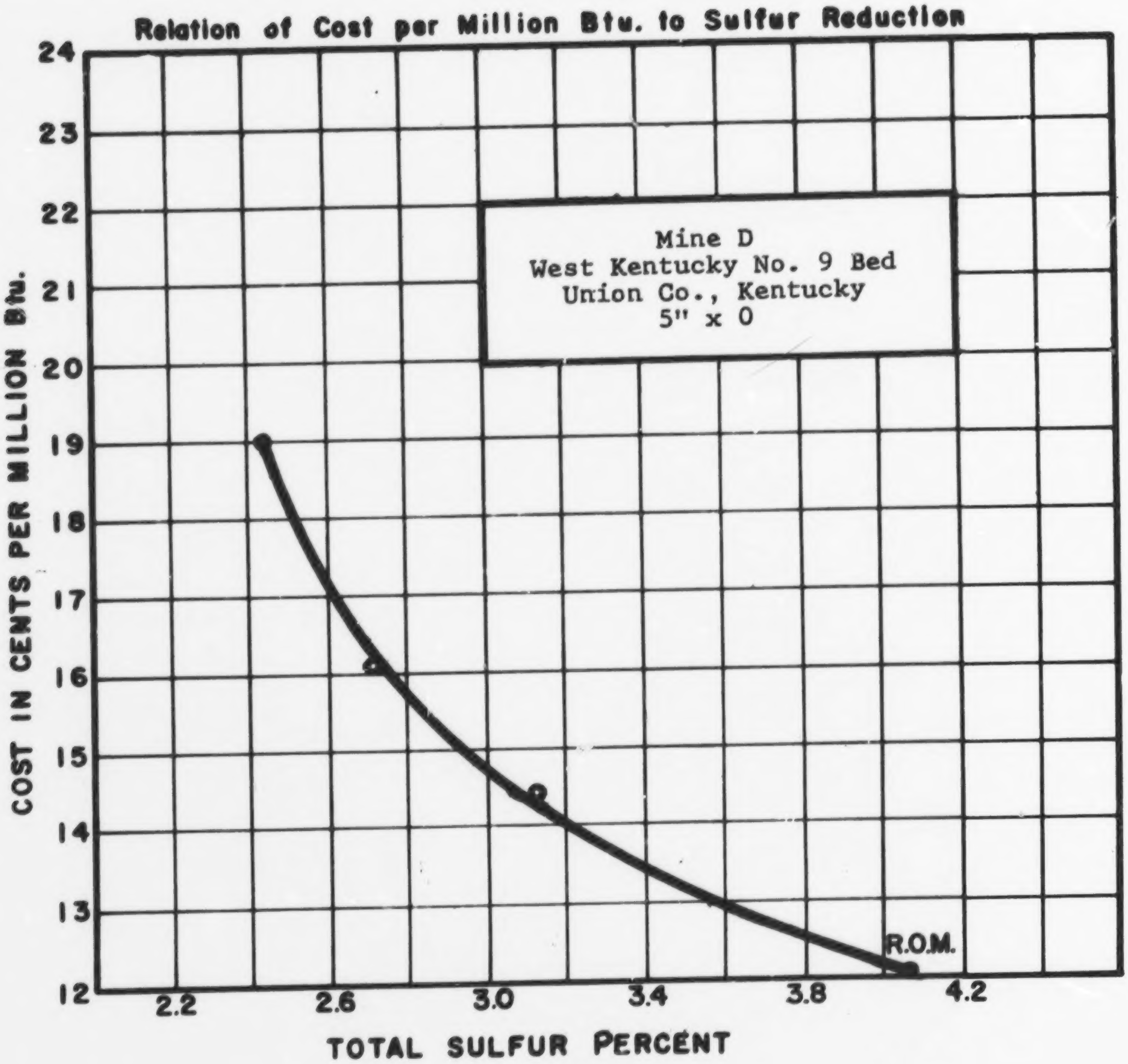

Relation of Cost per Million Btu. to Sulfur Reduction
Mine D
West Kentucky No. 9 Bed
Union Co., Kentucky
5" x 0
COST IN CENTS PER MILLION Btu.
24
23
22
21
20
19
18
17
16
15
14
13
12
2.2
2.6
3.0
3.4
3.8
4.2
R.O.M.
TOTAL SULFUR PERCENT

Table No. 16

MINE "D"

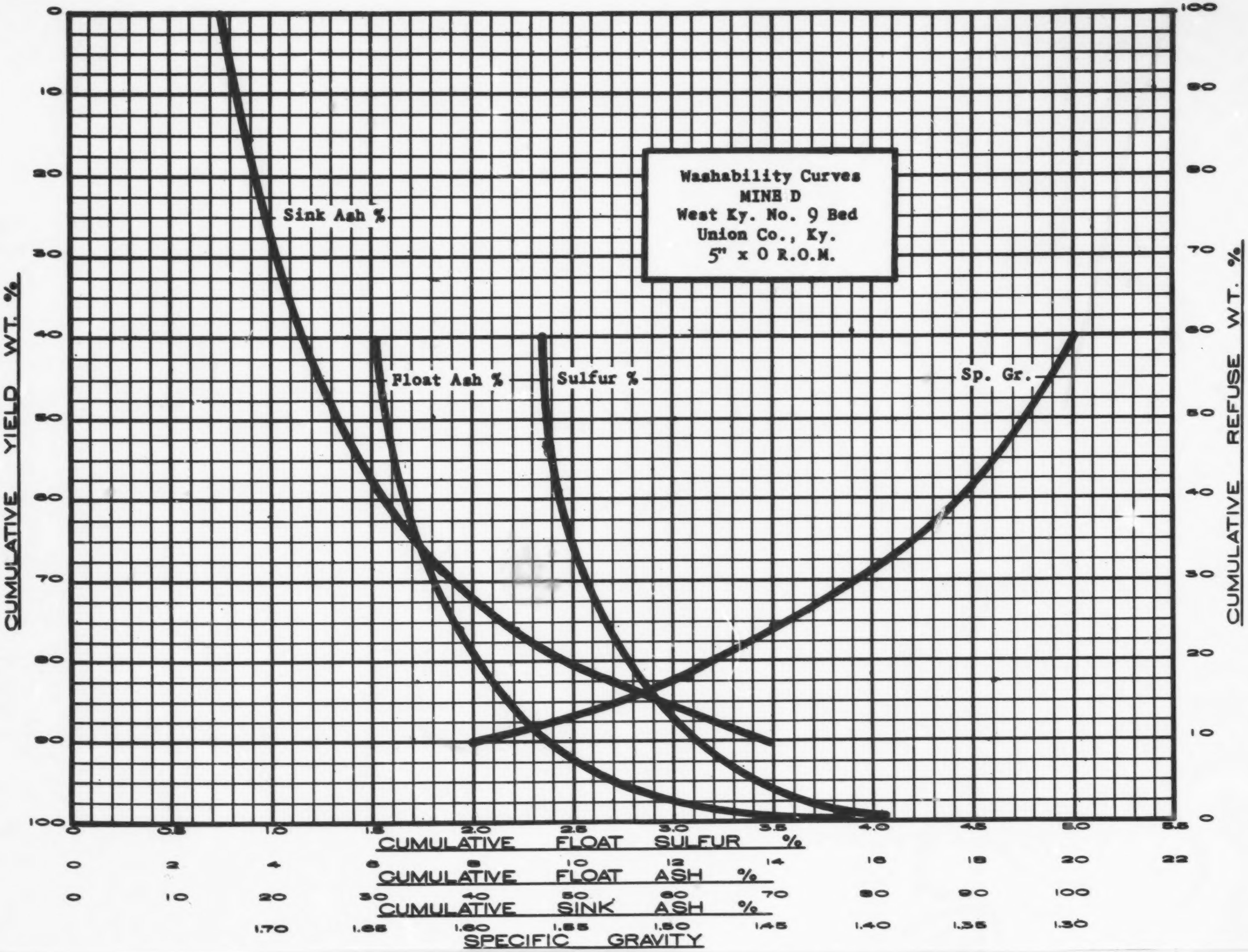
West Kentucky No. 9 Bed

Union County

Combined Washability Data, 5" x 0 R.O.M.

Specific Gravity		Weight %	Ash %	Sulphur %	Float Cumulative Weight %	Float Cumulative Ash %	Float Cumulative Sulphur %	Sink Cumulative Weight %	Sink Cumulative Ash %	Sink Cumulative Sulphur %
Float	1.30	40.00	6.05	2.35	40.00	6.05	2.35	100.00	15.50	4.07
1.30	1.35	18.43	7.92	2.63	58.43	6.65	2.44	60.00	23.37	6.10
1.35	1.40	10.09	10.07	3.32	68.52	7.23	2.57	41.57	30.22	7.18
1.40	1.45	7.81	12.52	4.01	76.33	7.76	2.72	31.48	36.71	8.46
1.45	1.50	6.18	17.03	4.52	82.51	8.47	2.86	23.67	44.65	9.93
1.50	1.60	7.52	33.80	10.70	90.03	9.45	3.10	17.49	54.30	11.86
1.60	Sink	9.97	69.80	12.72	100.00	15.50	4.07	9.97	69.80	12.72

Figure 31


Washability Curves
MINE D
West Ky. No. 9 Bed
Union Co., Ky.
5" x 0 R.O.M.
Sink Ash %
Float Ash %
Sulfur %
Sp. Gr.
CUMULATIVE YIELD WT. %
0
10
20
30
40
50
60
70
80
90
100
CUMULATIVE REFUSE WT. %
100
90
80
70
60
50
40
30
20
10
0
CUMULATIVE FLOAT SULFUR %
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
CUMULATIVE FLOAT ASH %
0
2
4
6
8
10
12
14
16
18
20
22
CUMULATIVE SINK ASH %
0
10
20
30
40
50
60
70
80
90
100
SPECIFIC GRAVITY
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30

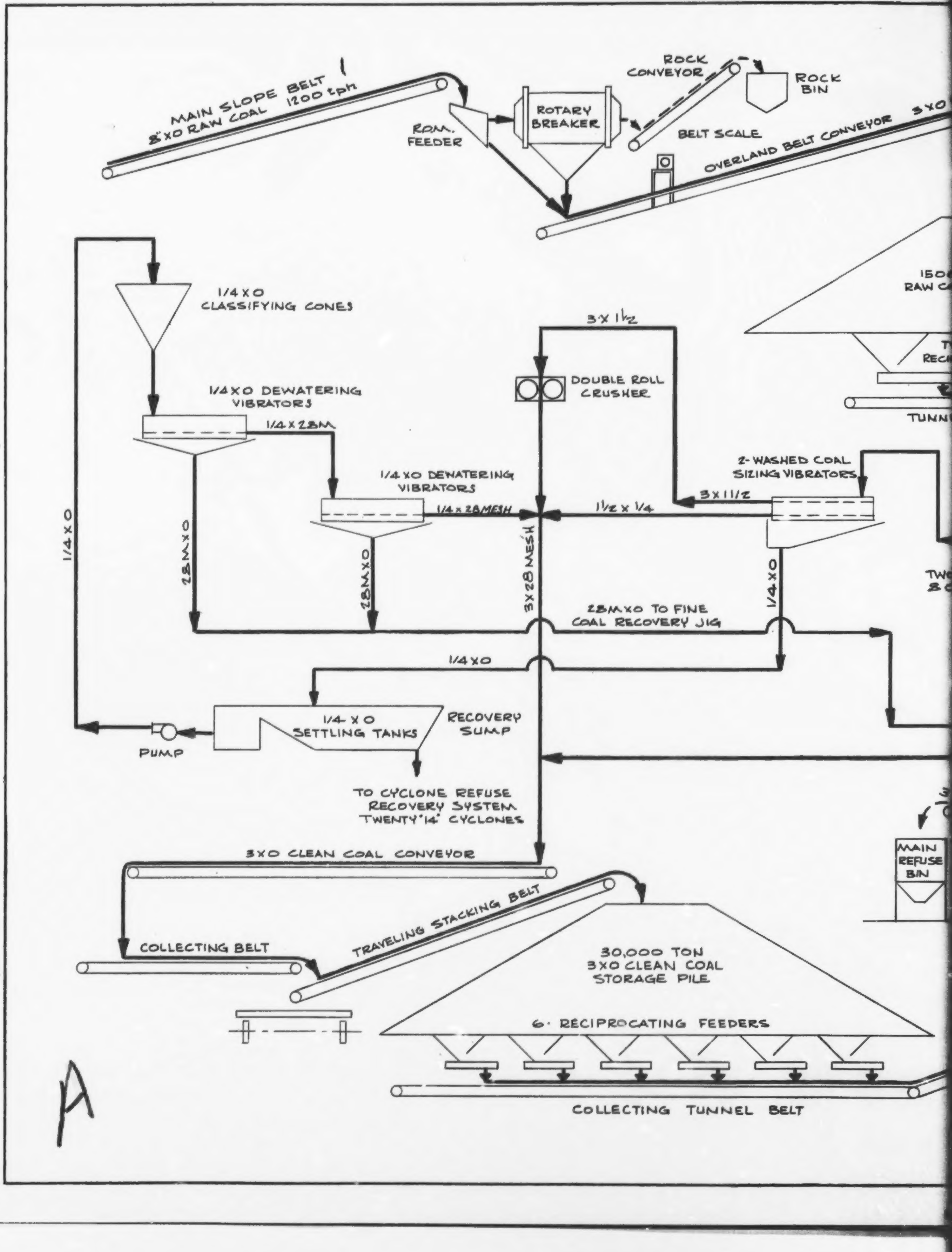
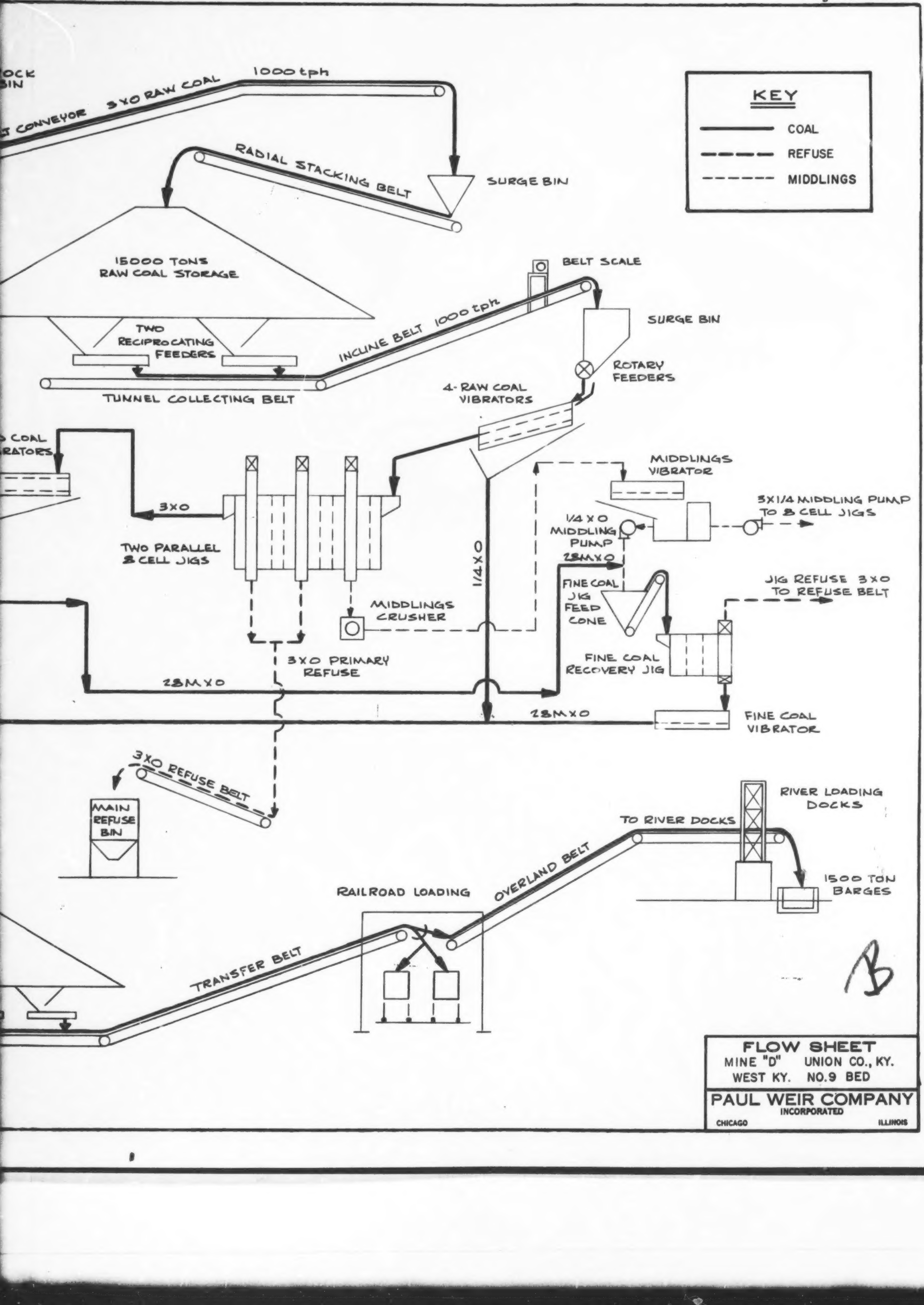

MAIN SLOPE BELT
8"X0 RAW COAL 1200 tph
1
R.O.M. FEEDER
ROTARY BREAKER
ROCK CONVEYOR
ROCK BIN
BELT SCALE
OVERLAND BELT CONVEYOR
3X0
1/4X0 CLASSIFYING CONES
3X1 1/2
DOUBLE ROLL CRUSHER
1/4X0 DEWATERING VIBRATORS
1/4X28M
1/4X0 DEWATERING VIBRATORS
1/4 x 28 MESH
1 1/2 x 1/4
3X1 1/2
2-WASHED COAL SIZING VIBRATORS
1/4X0
28MX0
28MX0
3X28 MESH
1/4X0
28MX0 TO FINE COAL RECOVERY JIG
1/4X0
1/4-X0 SETTLING TANKS
RECOVERY SUMP
PUMP
TO CYCLONE REFUSE RECOVERY SYSTEM TWENTY 14" CYCLONES
3X0 CLEAN COAL CONVEYOR
MAIN REFUSE BIN
TRAVELING STACKING BELT
COLLECTING BELT
30,000 TON 3X0 CLEAN COAL STORAGE PILE
6-RECIPROCATING FEEDERS
COLLECTING TUNNEL BELT
A

Figure 32


OCK
BIN
CONVEYOR 3X0 RAW COAL
1000 tph
RADIAL STACKING BELT
SURGE BIN
KEY
COAL
REFUSE
MIDDLINGS
15000 TONS
RAW COAL STORAGE
TWO
RECIPROCATING
FEEDERS
TUNNEL COLLECTING BELT
INCLINE BELT 1000 tph
BELT SCALE
SURGE BIN
ROTARY
FEEDERS
4- RAW COAL
VIBRATORS
COAL
RATORS
3X0
TWO PARALLEL
8 CELL JIGS
1/4 X 0
MIDDLINGS
VIBRATOR
1/4 X 0
MIDDLING
PUMP
28M X 0
3X1/4 MIDDLING PUMP
TO 8 CELL JIGS
FINE COAL
JIG
FEED
CONE
JIG REFUSE 3X0
TO REFUSE BELT
MIDDLINGS
CRUSHER
3X0 PRIMARY
REFUSE
FINE COAL
RECOVERY JIG
28M X 0
28M X 0
FINE COAL
VIBRATOR
3X0 REFUSE BELT
MAIN
REFUSE
BIN
RIVER LOADING
DOCKS
TO RIVER DOCKS
OVERLAND BELT
1500 TON
BARGES
RAILROAD LOADING
TRANSFER BELT
FLOW SHEET
MINE "D" UNION CO., KY.
WEST KY. NO.9 BED
PAUL WEIR COMPANY
INCORPORATED
CHICAGO ILLINOIS

B

Table 17

West Kentucky Coal

No. 11 Bed

Sulfur Washability Analysis 4" x 0 R.O.M.

Specific Gravity		Weight %	Sulfur %	Float Cumulative Weight %	Float Cumulative Sulfur %	Sink Cumulative Weight %	Sink Cumulative Sulfur %
Float	1.25	5.72	2.31	5.72	2.31	100.00	4.29
1.25	1.30	44.73	3.79	50.45	3.62	94.28	4.41
1.30	1.40	34.74	3.95	85.19	3.76	49.55	4.97
1.40	1.50	2.39	4.62	87.19	3.78	14.81	7.35
1.50	1.60	0.98	6.12	88.56	3.81	12.42	7.87
1.60	Sink	11.44	8.02	100.00	4.29	11.44	8.02

Table 18

West Kentucky Coal

No. 12 Bed

Sulfur Washability Analysis 4" x 0 R.O.M.

Specific Gravity		Weight %	Sulfur %	Float Cumulative Weight %	Float Cumulative Sulfur %	Sink Cumulative Weight %	Sink Cumulative Sulfur %
Float	1.25	1.77	1.50	1.77	1.50	100.00	2.37
1.25	1.30	17.25	1.84	19.02	1.81	98.23	2.38
1.30	1.40	63.41	2.01	82.43	1.96	80.98	2.50
1.40	1.50	5.53	2.42	87.96	1.99	17.57	4.26
1.50	1.60	1.27	2.54	89.23	2.00	12.04	5.10
1.60	Sink	10.77	5.41	100.00	2.37	10.77	5.41

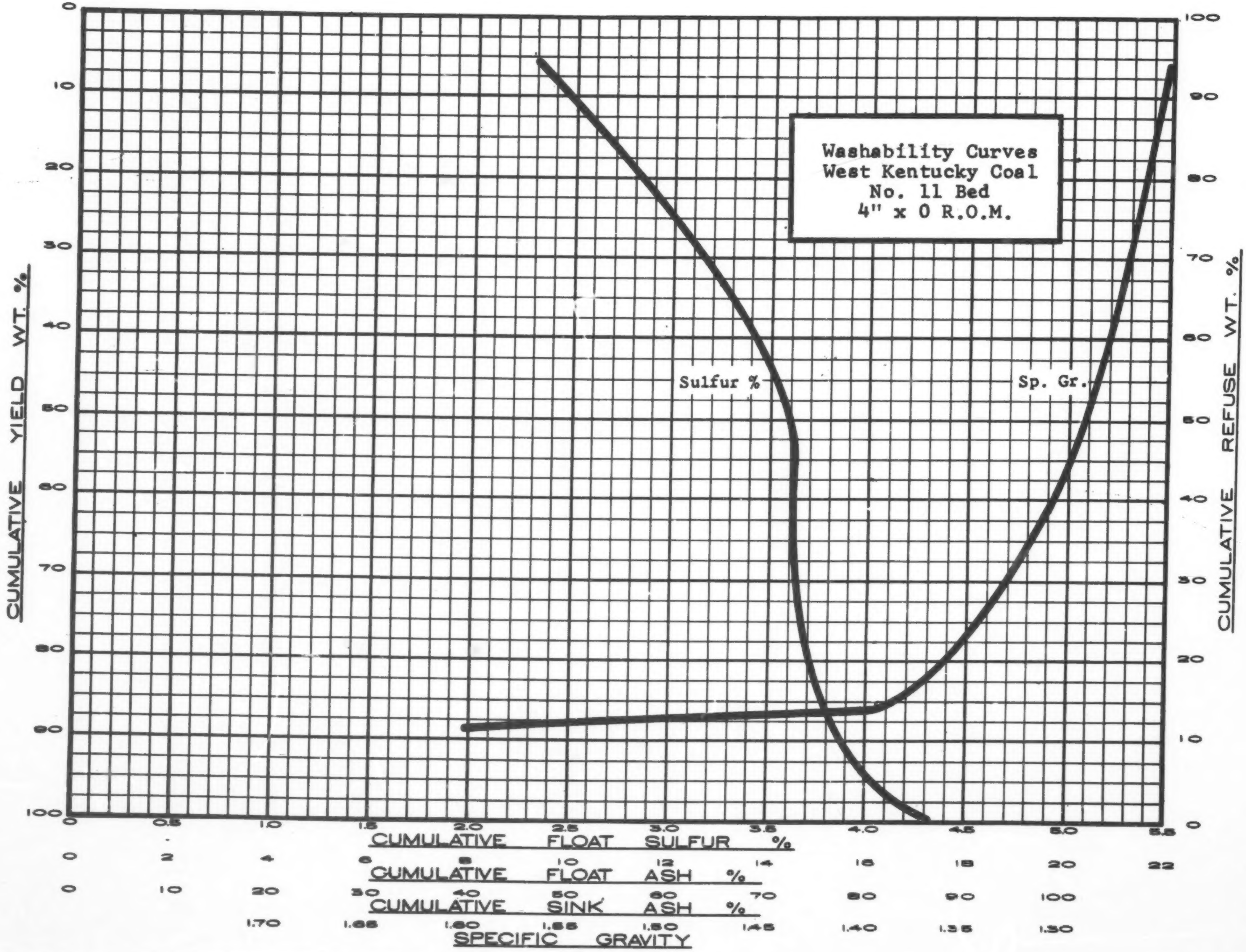

Washability Curves
West Kentucky Coal
No. 11 Bed
4" x 0 R.O.M.
Sulfur %
Sp. Gr.
CUMULATIVE YIELD WT. %
0
10
20
30
40
50
60
70
80
90
100
CUMULATIVE REFUSE WT. %
100
90
80
70
60
50
40
30
20
10
0
CUMULATIVE FLOAT SULFUR %
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
CUMULATIVE FLOAT ASH %
0
2
4
6
8
10
12
14
16
18
20
22
CUMULATIVE SINK ASH %
0
10
20
30
40
50
60
70
80
90
100
SPECIFIC GRAVITY
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30

Figure 33

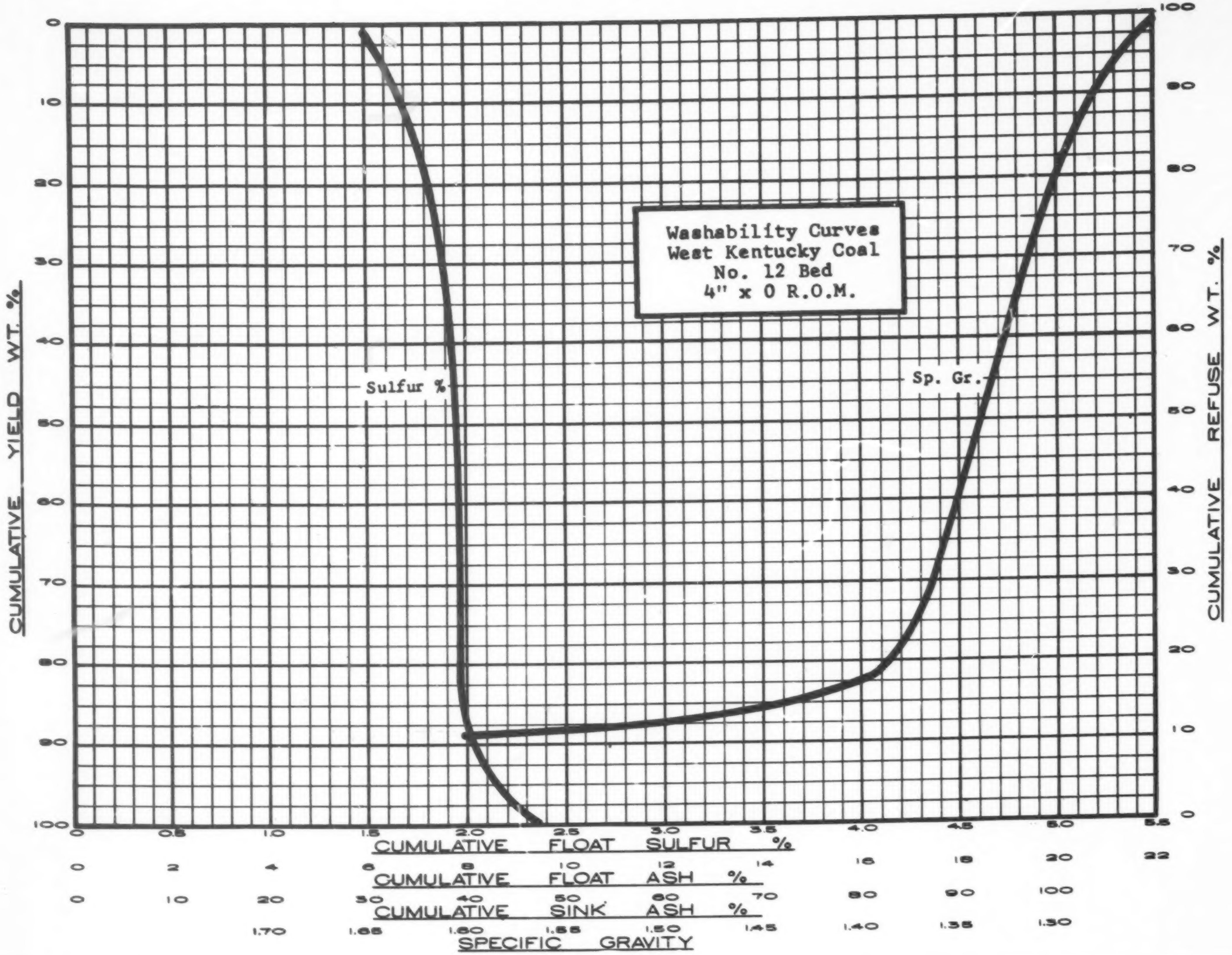

Washability Curves
West Kentucky Coal
No. 12 Bed
4" x 0 R.O.M.
Sulfur %
Sp. Gr.
CUMULATIVE YIELD WT. %
0
10
20
30
40
50
60
70
80
90
100
CUMULATIVE REFUSE WT. %
100
90
80
70
60
50
40
30
20
10
0
CUMULATIVE FLOAT SULFUR %
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
CUMULATIVE FLOAT ASH %
0
2
4
6
8
10
12
14
16
18
20
22
CUMULATIVE SINK ASH %
0
10
20
30
40
50
60
70
80
90
100
SPECIFIC GRAVITY
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30

Figure 34

4.6 Case Study, Mine "E"

Mine "E" is an underground or deep mine, operating in Western Pennsylvania on the Pittsburgh bed. In comparison to midwest practice, both mine cost and preparation plant costs are high. Feed rate is only 500 t.p.h. The plant, however, is new and employs heat dryers and complete water clarification system. It was built at a high capital cost and at the same time, relatively low feed rate, the combination giving high operating and depreciation costs.

Estimated f.o.b. costs per million Btu, at 1.60 separating density is 16.9 cents, at 1.45 it is 17.5 cents, and at 1.35 it is 19.6 cents.

The head sulfur for this Pittsburgh bed coal is 2.66 percent. This is reduced to 2.03 percent at 1.60, to 1.90 percent at 1.45, and 1.64 percent at 1.35 specific gravity. Organic sulfur averages 0.95 percent. This plant could wash coal at 1.35, butat a corresponding loss in efficiency and yield.

Figure No. 35 gives the sulfur reduction versus cost per million Btu curve. Table No. 19 shows float and sink data, Figure No. 36 washability curves, and Figure No. 37 shows a flow sheet of the plant.

Estimated costs for Mine "E" follow:

4.6 MINE "E"

Pittsburgh Bed - Greene County

Deep Mine Coal - Western Pennsylvania

Coal Crushed to 1 1/2" x 0

See Flow Sheet Figure No. 37

Estimated Costs per Ton of Product (f.o.b. Mine)

Preparation plant Capital Cost = $3,500,000 for 500 t.p.h., raw coal feed capacity. Costs exclusive of raw coal storage system.

I. If coal is washed at 1.60 separating density = 90.0 percent yield (@ 95 % efficiency)

(a) Operating Costs (plant)

Labor	$0.117/ton product
Maintenance	0.090
Supplies	0.110
Power	0.063
Refuse handling	0.035
Total Operating	$0.415/ton product

(b) Depreciation at 20 years straight line

@ 1,500,000 tons per year =	$0.117/ton product

(c) Mining Costs

Run of Mine	$3.60/ton
@ 90 percent yield	4.00/ton product

(d) Total costs, f.o.b. mine, washing at 1.60 separating density

Plant Operating	$0.415
Depreciation	0.117
Mining	4.000
Total	$4.522/ton product

(e) Total cost per million Btu @ 13,400 Btu/lb. = 16.9 cents f.o.b.

II. If coal is washed at 1.45 separating density = 85.0 percent yield (@ 93.5 % efficiency)

Plant Operating	$0.437/ton product
Plant Depreciation	0.123
Mining	4.210
Total costs f.o.b.	$4.770/ton product

Total costs f.o.b. - 17.5 cents per million Btu @ 13,600 Btu/lb.

Mine "E" - Continued

III. If coal is washed at 1.35 separating density = 72.0 percent yield
(@ 90.0 % efficiency)

Plant Operating	$0.506/ton product
Plant Depreciation	0.143
Mining	4.878
Total costs f.o.b.	$5.527/ton product

Total costs f.o.b. - 19.6 cents per million Btu
@ 14,100 Btu/lb.

IV. Total Sulfur - Clean Coal

@ 1.35 Specific Gravity = 1.64 %
1.45 " " = 1.90
1.60 " " = 2.03

Raw Coal Sulfur Content = 2.66

"Efficiency" is the measure of performance of this plant in terms of recovery or yield to meet the theoretical ash and sulfur shown in float and sink analyses.

Figure 35

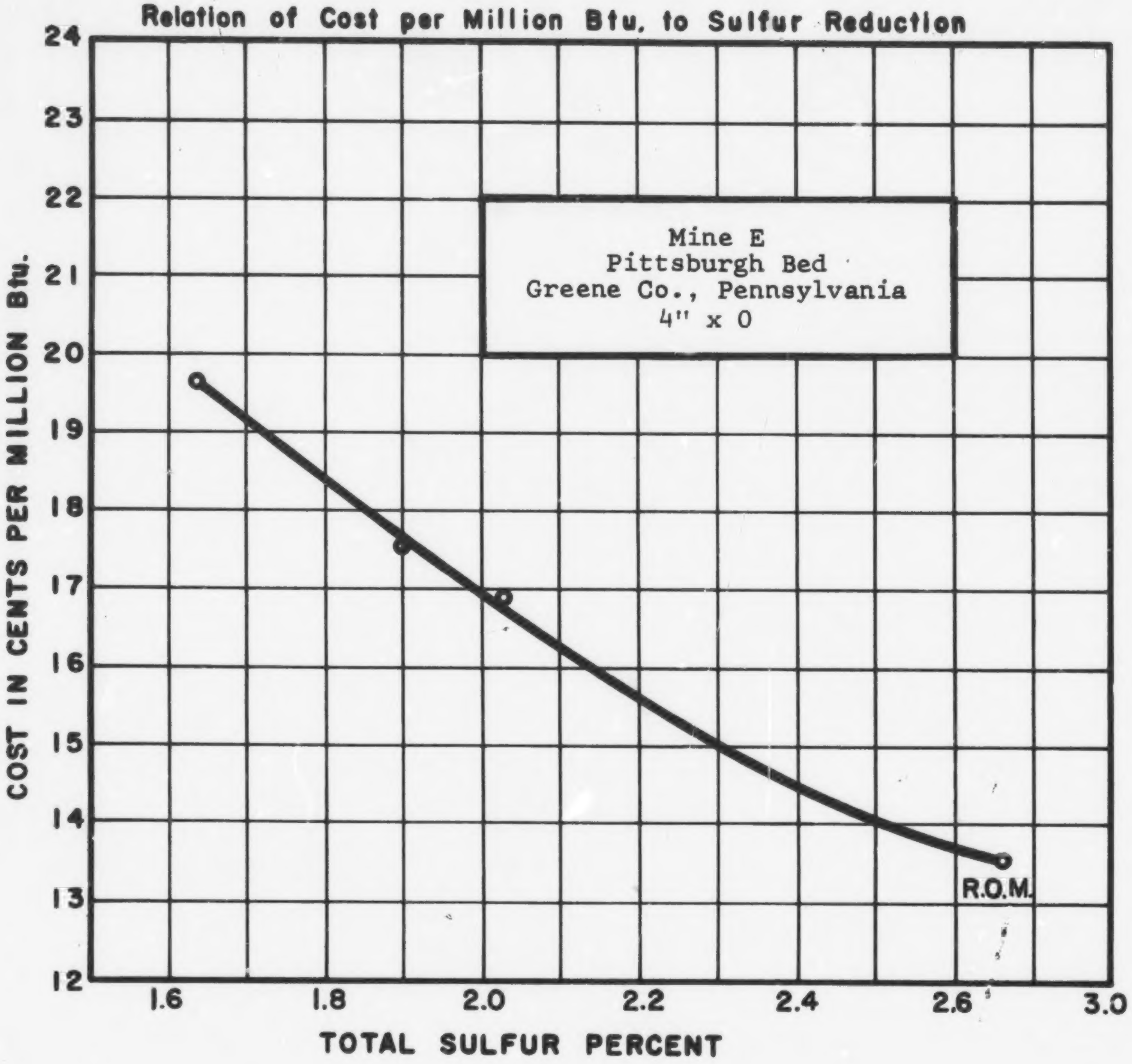

Relation of Cost per Million Btu. to Sulfur Reduction
Mine E
Pittsburgh Bed
Greene Co., Pennsylvania
4" x 0
COST IN CENTS PER MILLION Btu.
24
23
22
21
20
19
18
17
16
15
14
13
12
1.6
1.8
2.0
2.2
2.4
2.6
3.0
R.O.M.
TOTAL SULFUR PERCENT

Table No. 19

MINE E

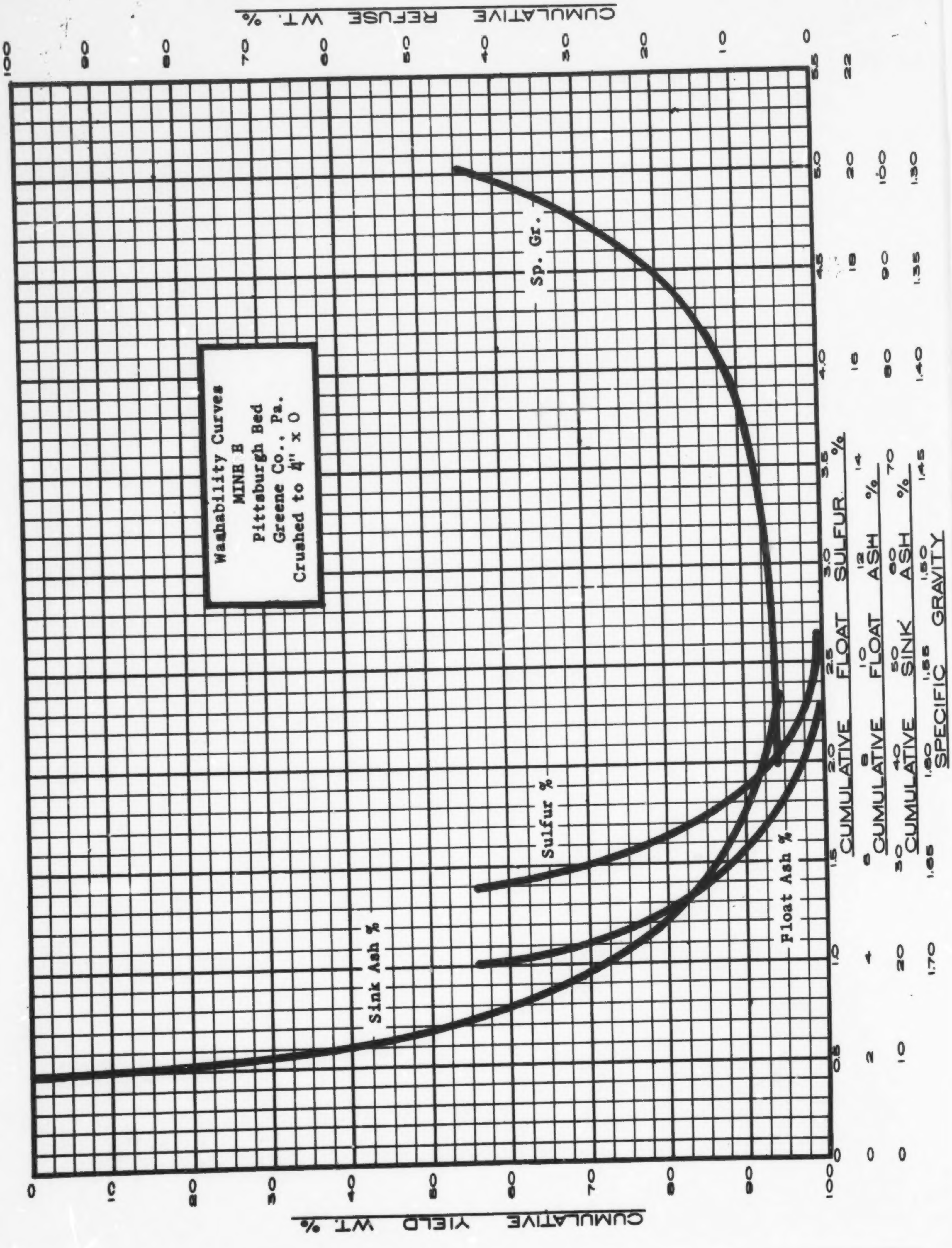
Pittsburgh Bed

Greene County, Pa.

Washability Data, 4" x 0

Specific Gravity	Weight %	Ash %	Sulfur %	Float Cumulative Weight %	Float Cumulative Ash %	Float Cumulative Sulfur %	Sink Cumulative Weight %	Sink Cumulative Ash %	Sink Cumulative Sulfur %
Float - 1.30	56.0	4.0	1.39	56.0	4.0	1.39	100.0	9.0	2.66
1.30 - 1.35	23.9	8.0	2.21	79.9	5.2	1.64	44.0	15.5	4.27
1.35 - 1.40	8.3	13.4	3.57	88.2	6.0	1.82	20.1	24.4	6.72
1.40 - 1.45	3.6	18.2	3.88	91.8	6.4	1.90	11.8	32.1	8.93
1.45 - 1.50	1.6	21.6	5.45	93.4	6.7	1.96	8.2	38.1	11.15
1.50 - 1.55	1.0	26.1	5.80	94.4	6.9	2.00	6.6	42.2	12.54
1.55 - 1.60	.5	28.9	6.89	94.9	7.0	2.03	5.6	45.0	13.74
1.60 - Sink	5.1	46.6	14.41	100.0	9.0	2.66	5.1	46.6	14.41

Figure 3b


Washability Curves
MINE B
Pittsburgh Bed
Greene Co., Pa.
Crushed to 4" x 0
Sp. Gr.
Sulfur %
Float Ash %
Sink Ash %
CUMULATIVE REFUSE WT. %
100 90 80 70 60 50 40 30 20 10 0
CUMULATIVE YIELD WT. %
0 10 20 30 40 50 60 70 80 90 100
CUMULATIVE FLOAT SULFUR %
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5
CUMULATIVE FLOAT ASH %
0 2 4 6 8 10 12 14 16 18 20 22
CUMULATIVE SINK ASH %
0 10 20 30 40 50 60 70 80 90 100
SPECIFIC GRAVITY
1.70 1.65 1.60 1.55 1.50 1.45 1.40 1.35 1.30

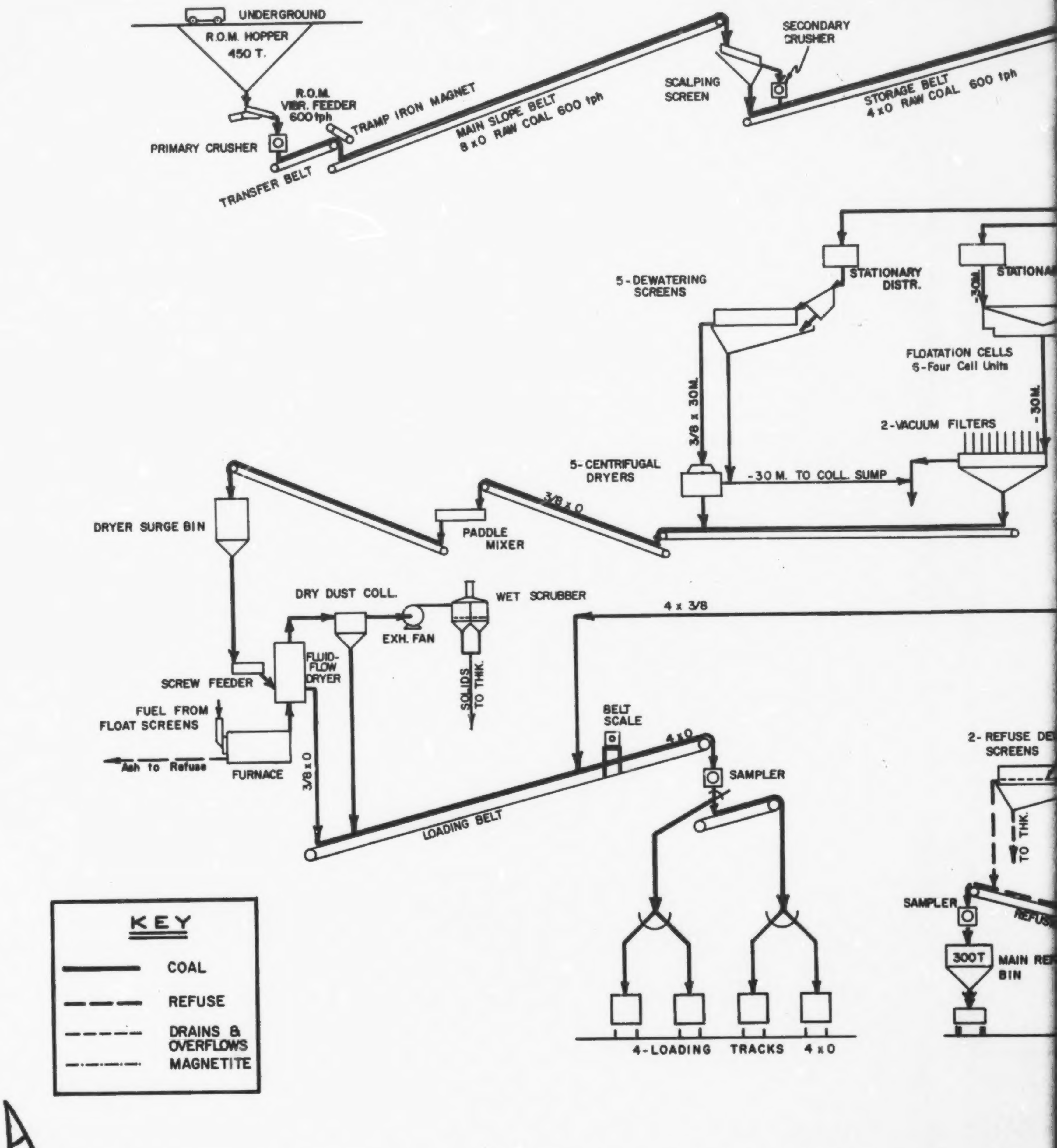
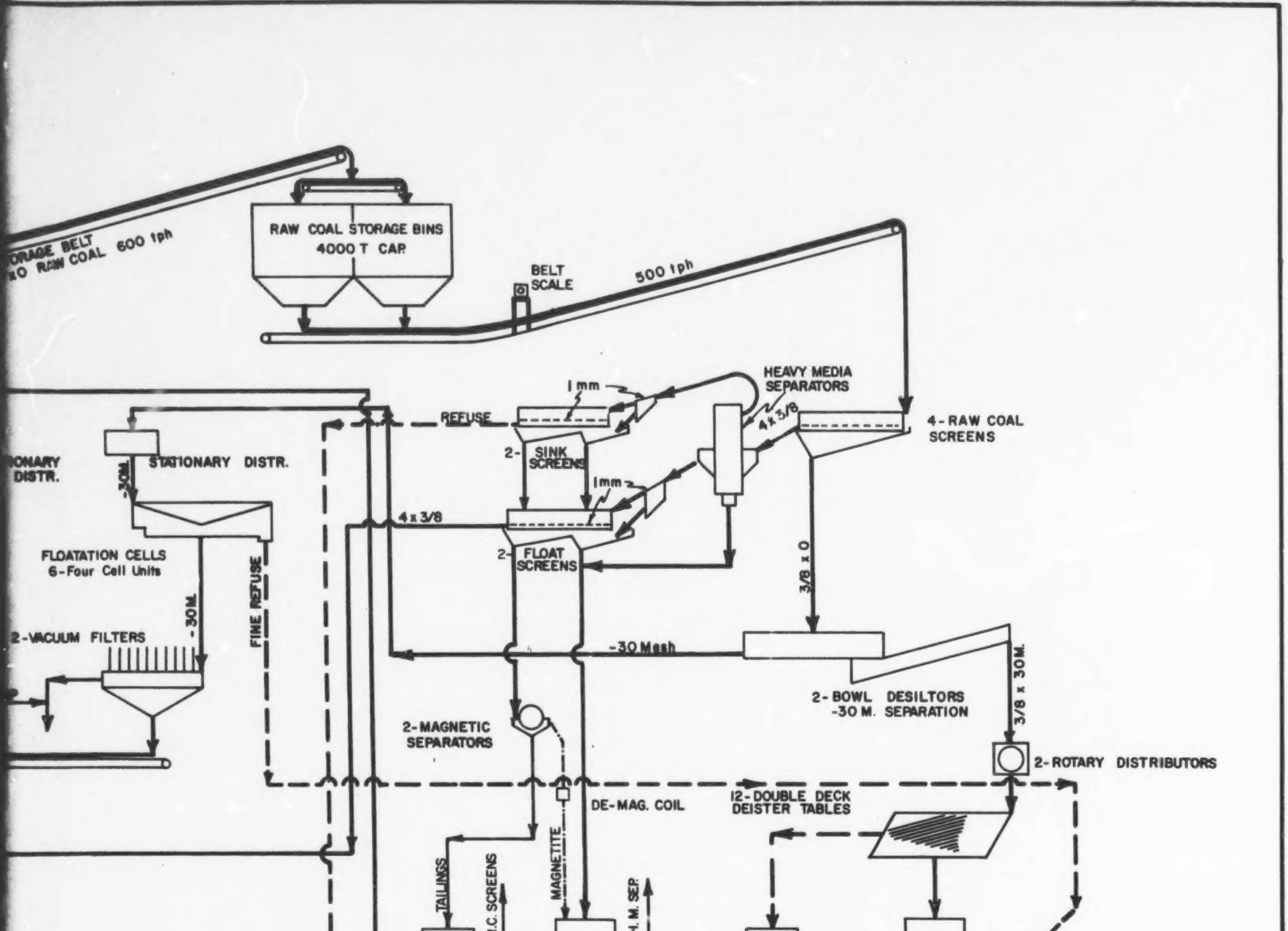

UNDERGROUND
R.O.M. HOPPER
450 T.
R.O.M.
VIBR. FEEDER
600 tph
PRIMARY CRUSHER
TRANSFER BELT
TRAMP IRON MAGNET
MAIN SLOPE BELT
8 x 0 RAW COAL 600 tph
SCALPING
SCREEN
SECONDARY
CRUSHER
STORAGE BELT
4 x 0 RAW COAL 600 tph
STATIONARY
DISTR.
STATIONAR
-30M.
5-DEWATERING
SCREENS
FLOATATION CELLS
6-Four Cell Units
-30M.
2-VACUUM FILTERS
3/8 x 30M.
5-CENTRIFUGAL
DRYERS
-30 M. TO COLL. SUMP
DRYER SURGE BIN
PADDLE
MIXER
3/8 x 0
DRY DUST COLL.
WET SCRUBBER
EXH. FAN
SOLIDS
TO THK.
FLUID-
FLOW
DRYER
SCREW FEEDER
FUEL FROM
FLOAT SCREENS
Ash to Refuse
FURNACE
3/8 x 0
4 x 3/8
BELT
SCALE
4 x 0
SAMPLER
LOADING BELT
4-LOADING TRACKS 4 x 0
2-REFUSE DE
SCREENS
TO THK.
SAMPLER
REFUS
300T
MAIN RE
BIN
KEY
COAL
REFUSE
DRAINS &
OVERFLOWS
MAGNETITE
A

Figure 37


ORAGE BELT
x0 RAW COAL 600 tph
RAW COAL STORAGE BINS
4000 T CAP.
BELT SCALE
500 tph
HEAVY MEDIA SEPARATORS
1mm
REFUSE
4x3/8
4-RAW COAL SCREENS
2-SINK SCREENS
1mm
IONARY DISTR.
STATIONARY DISTR.
-30M.
4x3/8
2-FLOAT SCREENS
FLOATATION CELLS
6-Four Cell Units
3/8 x 0
FINE REFUSE
-30M.
2-VACUUM FILTERS
-30 Mesh
2-BOWL DESILTORS
-30 M. SEPARATION
3/8 x 30M.
2-MAGNETIC SEPARATORS
2-ROTARY DISTRIBUTORS
DE-MAG. COIL
12-DOUBLE DECK DEISTER TABLES
TAILINGS
TO R.C. SCREENS
MAGNETITE
TO H.M. SEP.
BLACK WAT. SUMPS
HEAVY MEDIA SUMPS
3/8 x 30M.
REFUSE SUMPS
C.C. SUMPS
2-REFUSE DEWAT SCREENS
1mm
TO THK.
REFUSE CRUSHER
TAILINGS THICKENER
SAMPLER
REFUSE BELT
300T
MAIN REFUSE BIN
TO R.C. SCREENS
-30M.
COLLECTING SUMP
TO REFUSE POND
REFUSE SUMP
TO PLANT
CLARIFIED WATER SUMP
FLOW SHEET
MINE "E" GREENE COUNTY, PA.
PITTSBURGH BED
PAUL WEIR COMPANY
INCORPORATED
CHICAGO
ILLINOIS

4.7 Case Study, Mine "F"

Mine "F" is located in Ohio, a combined deep and strip mine operation in the Ohio No. 8 bed. The plant has a capacity of 1,500 t.p.h. of raw coal feed. At full capacity this large plant operates two shifts daily.

The cleaning equipment consists essentially of Baum type jigs, Chance dense media cones, Deister tables and is equipped with heat dryers.

At a 1.60 separating density the mine cost at an 85 percent yield is estimated to be $3.12 per ton and cleaning plant costs of $0.395. With 13,000 Btu coal, f.o.b. cost per million Btu is estimated at 13.5 cents. At 1.45 this would be increased to 14.8 cents and at 1.35, this would be 16.8 cents per million Btu.

Raw coal sulfur from the test data is 3.55 percent and is reduced to 2.62 percent at 1.60, 2.25 percent at 1.45, and 1.94 percent at 1.35 specific gravity. This plant is not designed to separate at 1.35. Organic sulfur is 1.50 percent.

Figure No. 38 illustrates the costs per million Btu of sulfur reduction. Table No. 20 presents typical float and sink data, Figure No. 39 the washability curves, and Figure No. 40 the flow sheet of the preparation plant.

Estimated costs for Mine "F" follow:

4.7 MINE "F"

Ohio - No. 8 Bed

Harrison and Belmont Counties

Combined Deep and Strip Mine Operations

7" x 0 Raw Coal. See Flow Sheet Figure No. 40

Estimated Costs per Ton of Product (f.o.b. Mine)

Preparation Plant Capital Cost = $7,500,000 for 1,500 t.p.h. raw coal feed capacity

I. If coal is washed at 1.60 separating density = 85.0 % yield (@ 98 % efficiency)

(a) Operating Costs (plant)

Labor	$0.096/ton product
Maintenance	0.082
Supplies	0.077
Power	0.038
Refuse handling	0.027
Total Operating	$0.320/ton product

(b) Depreciation at 20 years straight line, @ 5,000,000 tons per year, on basis of two shift operation $0.075/ton product

(c) Mining Costs

Run of Mine	$2.65/ton
@ 85 % yield	$3.12/ton product

(d) Total Costs, f.o.b. mine, washing at 1.60 specific gravity

Plant Operating	$0.320/ton product
Depreciation	0.075
Mining	3.120
Total	$3.515/ton product

(e) Total cost per million Btu @ 13,000 Btu/lb. = 13.5 cents f.o.b. mine.

II. If coal is washed at 1.45 separating density = 74.0 % yield (@ 96.0 % efficiency)

Plant Operating	$0.360/ton product
Plant Depreciation	0.084
Mining	3.501
Total Costs f.o.b. -	$3.945/ton product

Total Costs f.o.b. - 14.8 cents per million Btu @ 13,300 Btu/lb.

Mine "F" - Continued

III. If coal is washed at 1.35 separating density = 60.0 % yield (Theoretical as this type of plant cannot separate at 1.35).

Plant Operating	$0.418/ton product
Plant Depreciation	0.098
Mining	4.071
Total Costs f.o.b.-	$4.587/ton product
Total Costs f.o.b.-	16.8 cents per million Btu @ 13,600 Btu/lb.

IV. Total Sulfur - Clean Coal

@ 1.35 Specific Gravity = 1.94*
1.45 " " = 2.25
1.60 " " = 2.62

Raw Coal Sulfur = 3.55

Note:

* Theoretical, plant cannot separate at this density.

"Efficiency" is the measure of performance of this plant in terms of recovery or yield to meet the theoretical ash and sulfur shown in float and sink analyses.

Relation of Cost per Million Btu. to Sulfur Reduction

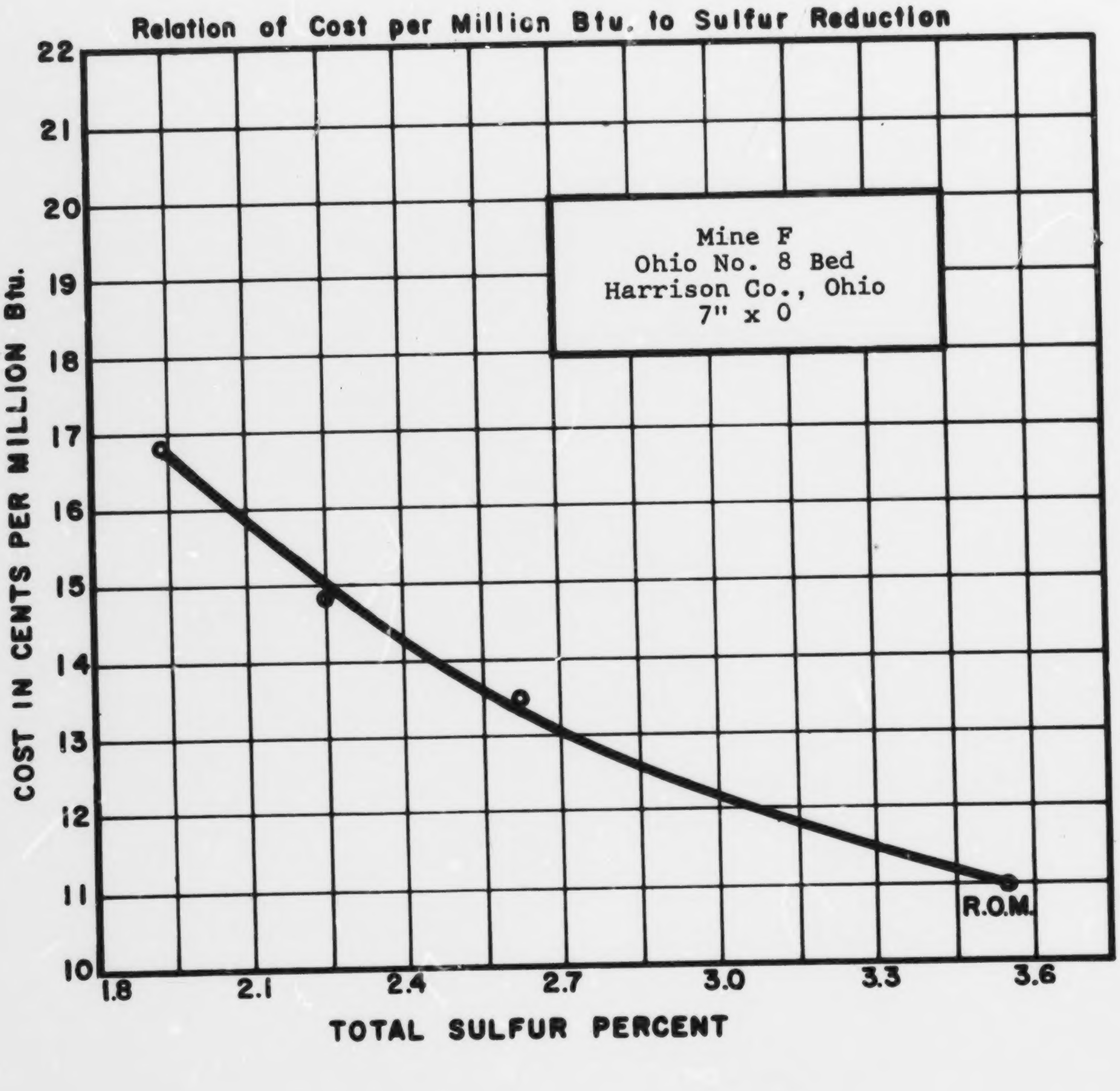


Table No. 20

MINE "F"

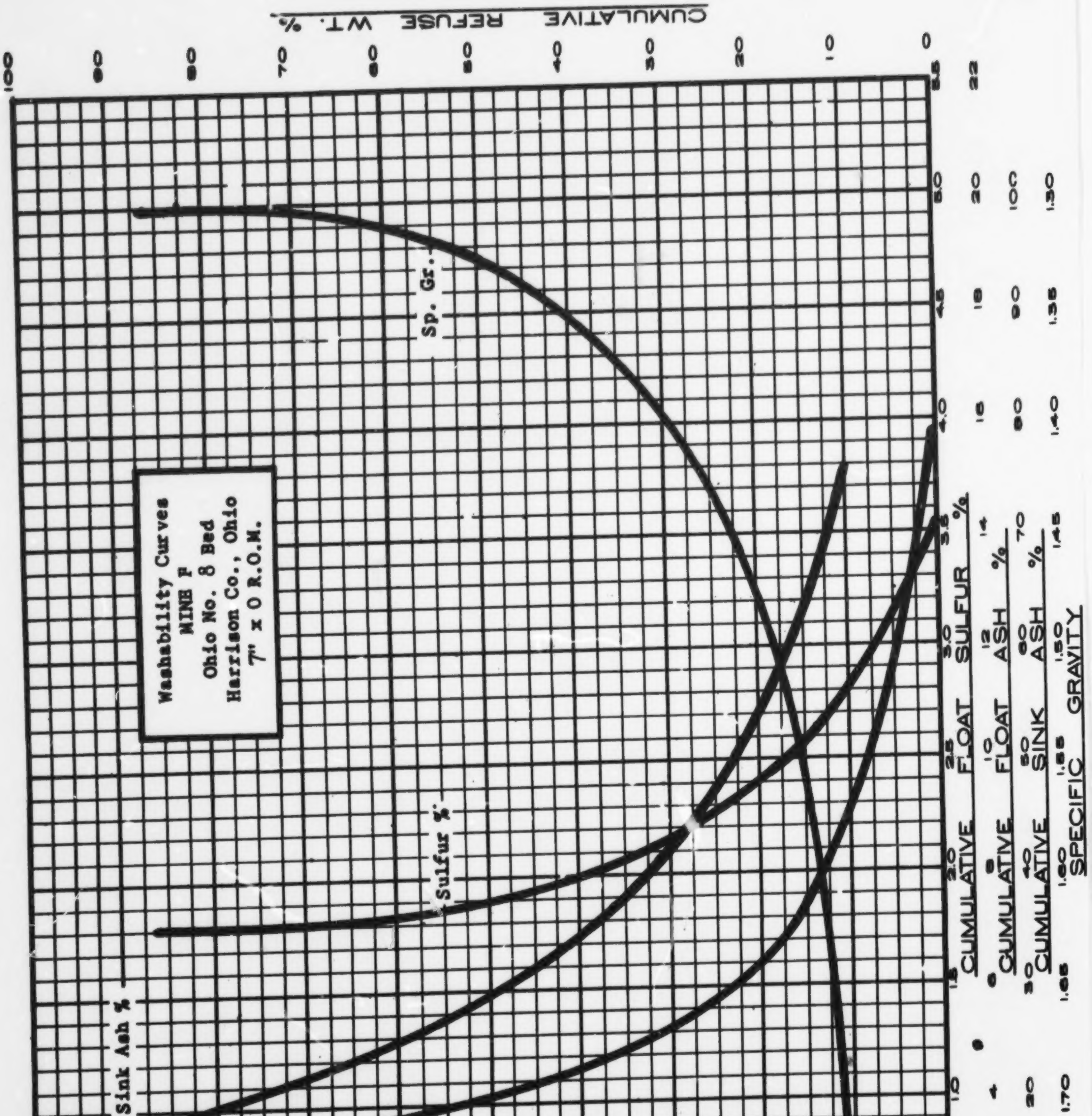
Ohio No. 8 Bed

Harrison County

Combined Washability Data, 7" x 0 R.O.M.

Specific Gravity		Weight %	Ash %	Sulfur %	Float Cumulative Weight %	Float Cumulative Ash %	Float Cumulative Sulfur %	Sink Cumulative Weight %	Sink Cumulative Ash %	Sink Cumulative Sulfur %
Float	1.30	13.00	3.05	1.79	13.00	3.05	1.79	100.00	15.80	3.55
1.30	1.40	57.52	5.96	2.23	70.52	5.43	2.15	87.00	18.20	3.82
1.40	1.50	11.48	17.91	6.92	82.00	6.71	2.48	29.48	42.20	7.30
1.50	1.60	4.55	33.88	5.15	86.55	8.16	2.62	18.00	57.54	8.25
1.60	1.80	3.45	36.65	9.10	90.00	9.22	2.87	13.45	65.40	9.41
1.80	Sink	10.00	75.20	9.70	100.00	15.80	3.55	10.00	75.20	9.70

Figure 39


Washability Curves
MINE F
Ohio No. 8 Bed
Harrison Co., Ohio
7" x 0 R.O.M.
CUMULATIVE REFUSE WT. %
0
10
20
30
40
50
60
70
80
90
100
CUMULATIVE YIELD WT. %
0
10
20
30
40
50
60
70
80
90
100
CUMULATIVE FLOAT SULFUR %
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
CUMULATIVE FLOAT ASH %
0
2
4
6
8
10
12
14
16
18
20
22
CUMULATIVE SINK ASH %
0
10
20
30
40
50
60
70
80
90
100
SPECIFIC GRAVITY
1.70
1.65
1.60
1.55
1.50
1.45
1.40
1.35
1.30
Sp. Gr.
Sulfur %
Sink Ash %
Float Ash %

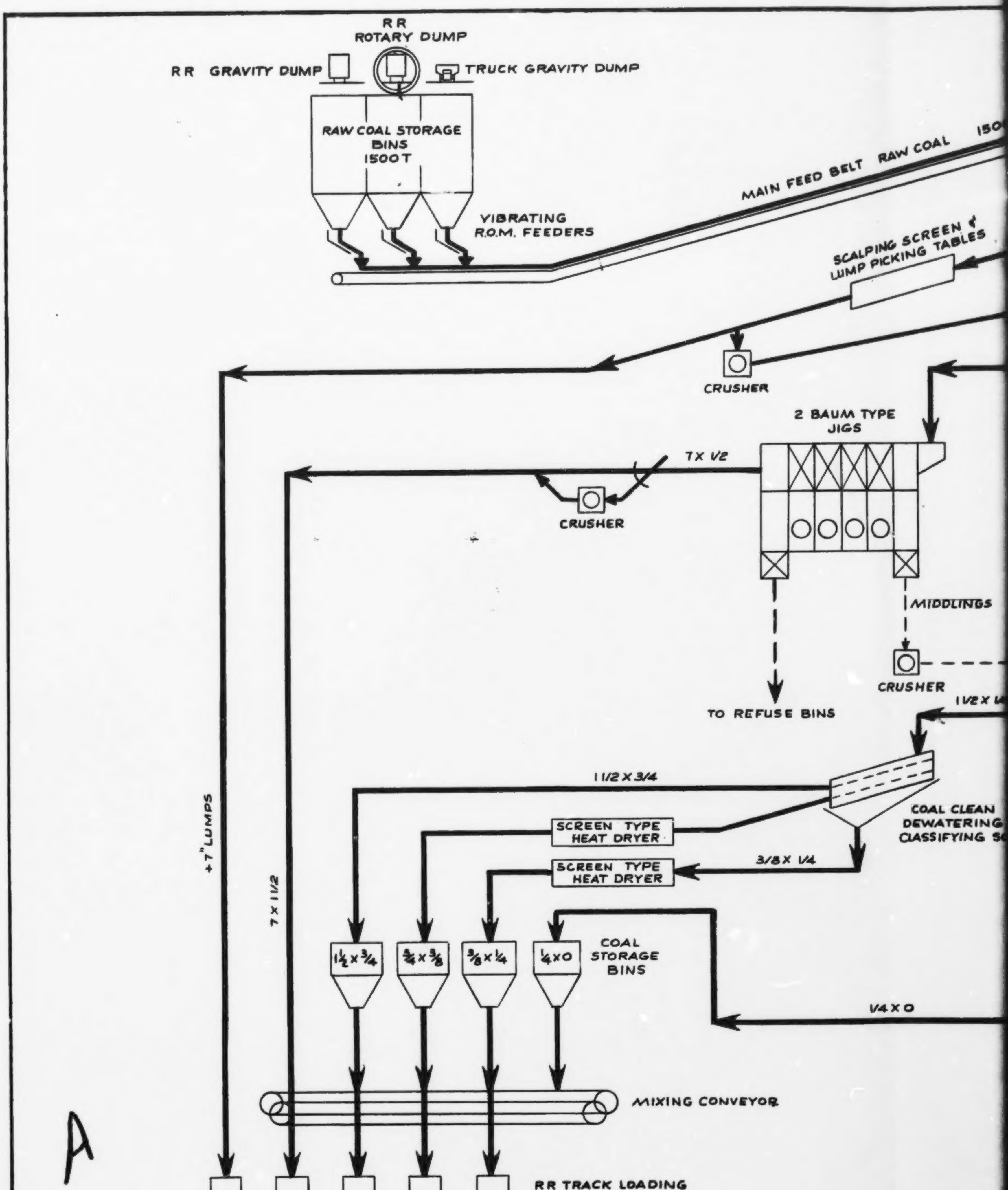
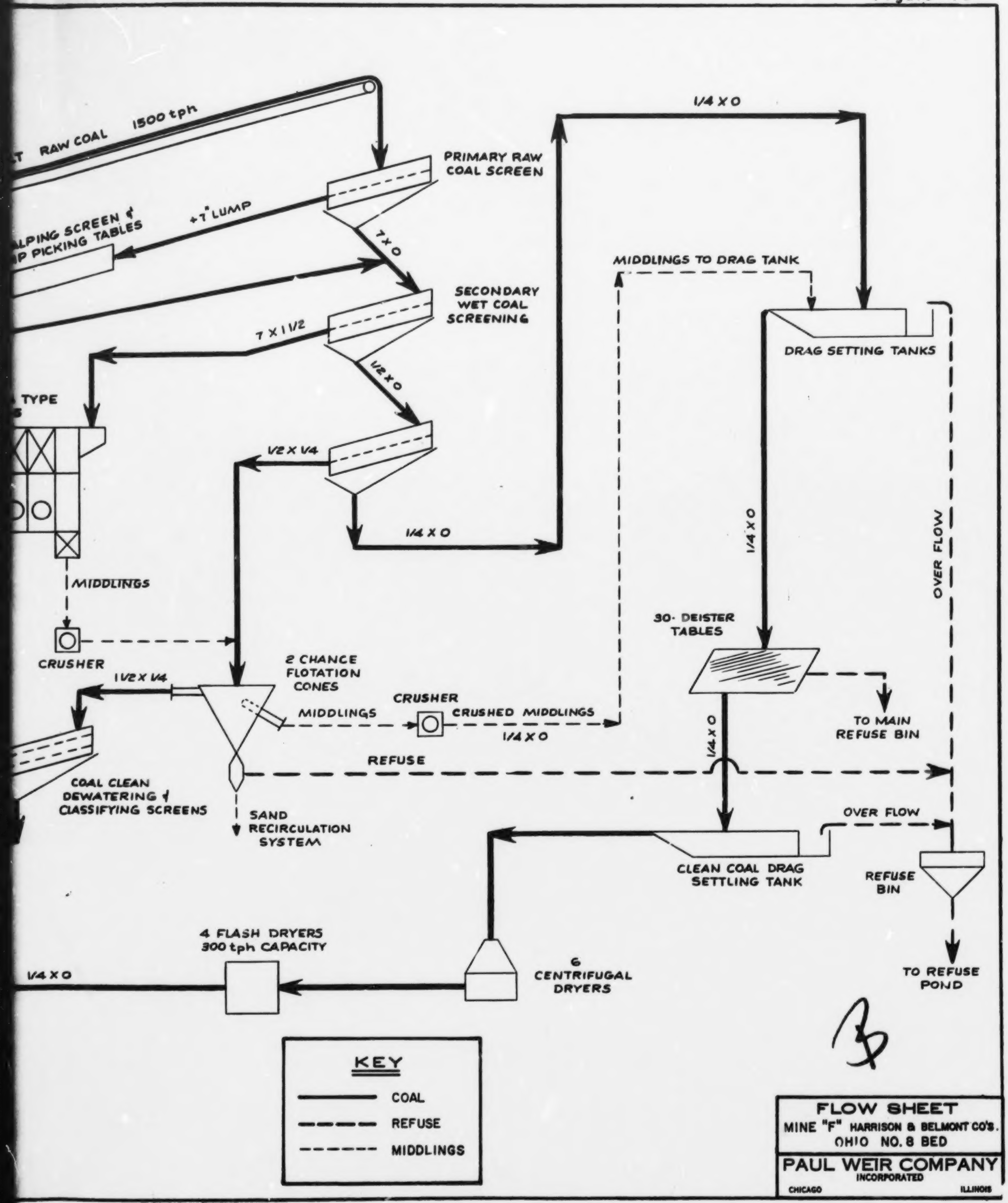

RR
ROTARY DUMP
RR GRAVITY DUMP
TRUCK GRAVITY DUMP
RAW COAL STORAGE BINS 1500T
MAIN FEED BELT RAW COAL 150
VIBRATING R.O.M. FEEDERS
SCALPING SCREEN & LUMP PICKING TABLES
CRUSHER
2 BAUM TYPE JIGS
7 X 1/2
CRUSHER
MIDDLINGS
CRUSHER
TO REFUSE BINS
1 1/2 X 1
1 1/2 X 3/4
COAL CLEAN DEWATERING CLASSIFYING S
SCREEN TYPE HEAT DRYER
SCREEN TYPE HEAT DRYER
3/8 X 1/4
+7" LUMPS
7 X 1 1/2
1½ x ¾
¾ x ⅜
⅜ x ¼
¼ x 0
COAL STORAGE BINS
1/4 X 0
MIXING CONVEYOR
A
RR TRACK LOADING

Figure 40


..T RAW COAL 1500 tph
PRIMARY RAW COAL SCREEN
..ALPING SCREEN & ..P PICKING TABLES
+7" LUMP
7 X 0
SECONDARY WET COAL SCREENING
7 X 1 1/2
1/2 X 0
.. TYPE
..S
1/2 X 1/4
1/4 X 0
1/4 X 0
MIDDLINGS TO DRAG TANK
DRAG SETTING TANKS
1/4 X 0
OVER FLOW
MIDDLINGS
CRUSHER
2 CHANCE FLOTATION CONES
1 1/2 X 1/4
MIDDLINGS
CRUSHER
CRUSHED MIDDLINGS
1/4 X 0
30- DEISTER TABLES
TO MAIN REFUSE BIN
1/4 X 0
REFUSE
COAL CLEAN DEWATERING & CLASSIFYING SCREENS
SAND RECIRCULATION SYSTEM
OVER FLOW
CLEAN COAL DRAG SETTLING TANK
REFUSE BIN
4 FLASH DRYERS 300 tph CAPACITY
6 CENTRIFUGAL DRYERS
TO REFUSE POND
1/4 X 0
KEY
COAL
REFUSE
MIDDLINGS

FLOW SHEET
MINE "F" HARRISON & BELMONT CO'S.
OHIO NO. 8 BED

PAUL WEIR COMPANY
INCORPORATED
CHICAGO ILLINOIS

SECTION 5.0 Potential Desulfurization Methods

5.1 General Comments on Desulfurization of Coal

Previous sections have described the nature of sulfur in coal and its wide variation as to organic and pyritic sulfur contents, as well as the widely variable dissemination of pyritic particles as to grain size. It is shown that the sulfur (or pyritic) content of some coals can be reduced reasonably well by a certain amount of crushing and washing at various specific gravities of separation. It is also shown that for many of the high sulfur coals, it will take extreme fine grinding for pyritic liberation and finally there are some coals which will have a high sulfur content no matter what is done to liberate pyrite.

Where crushing the coal does show substantial liberation of pyrite, numerous experiments and research have been conducted as to possible methods of removing pyritic particles. Since dry methods of separation have obvious advantages over wet methods of separation, much research has been conducted in dry grinding followed by various dry methods of separation. Some of these are described in this report.

5.2.1 Removal of Pyrite by Dry Methods

The Bituminous Coal Research, Inc., the Coal Research Bureau, the University of West Virginia and Battelle Memorial Institute have been engaged in research on possible dry methods for removing pyrite from finely crushed or pulverized coal. Systems of air classification, a variety of electrostatic techniques and magnetic separation have been investigated.

Interest at first centered on the possibilities of magnetic demineralization of coal. This was stimulated by work done by Yourovsky, et al, in 1958, in Soviet Russia who claimed that pyrite in pulverized coal in the presence of superheated steam develop films of ferro-magnetic minerals which could be removed with high intensity magnetic fields. However, intensive experiments by W. M. Kester at the Coal Research Bureau, West Virginia University, have shown that it may be technically feasible to remove some pyrite from finely pulverized coal by electromagnetic methods, but the capacity and economics are questionable.

Battelle Institute investigated the behaviour of pulverized coal particles in an electrostatic field. The Battelle staff concluded that there was no prospect of separating pyrite from finely powdered coal by processes that depended upon particle resistivity or dielectric constants. They concluded that differences in triboelectric charges may have application, but further investigation of this method indicated an unrealistic number of cycles would be necessary and, therefore, uneconomic.

They also tried non-uniform electrostatic fields and although it shows some promise of fairly effective separation with closely sized particles, here again the economics of such a separation appear unsatisfactory. References are given in Section 6.0.

5.2.2 Removal of Pyrite by Air Classifier

Bituminous Coal Research, Inc., has conducted a considerable amount of research in attempting to remove the sulfur content of steam coal by fine pulverization and air separation in a high efficiency air classifier. The paper describing their work in this field is mentioned in Section 3.7.1 of this report and their report reference is listed in Section 6.0. They are continuing further experiments in this method.

They have found that for many coals, much of the pyrite grains are within a 250-70 micron (60 to 200 mesh) size range, which is relatively large when compared to the size of coal as pulverized for combustion in large boilers (85-90 percent through 200 mesh).

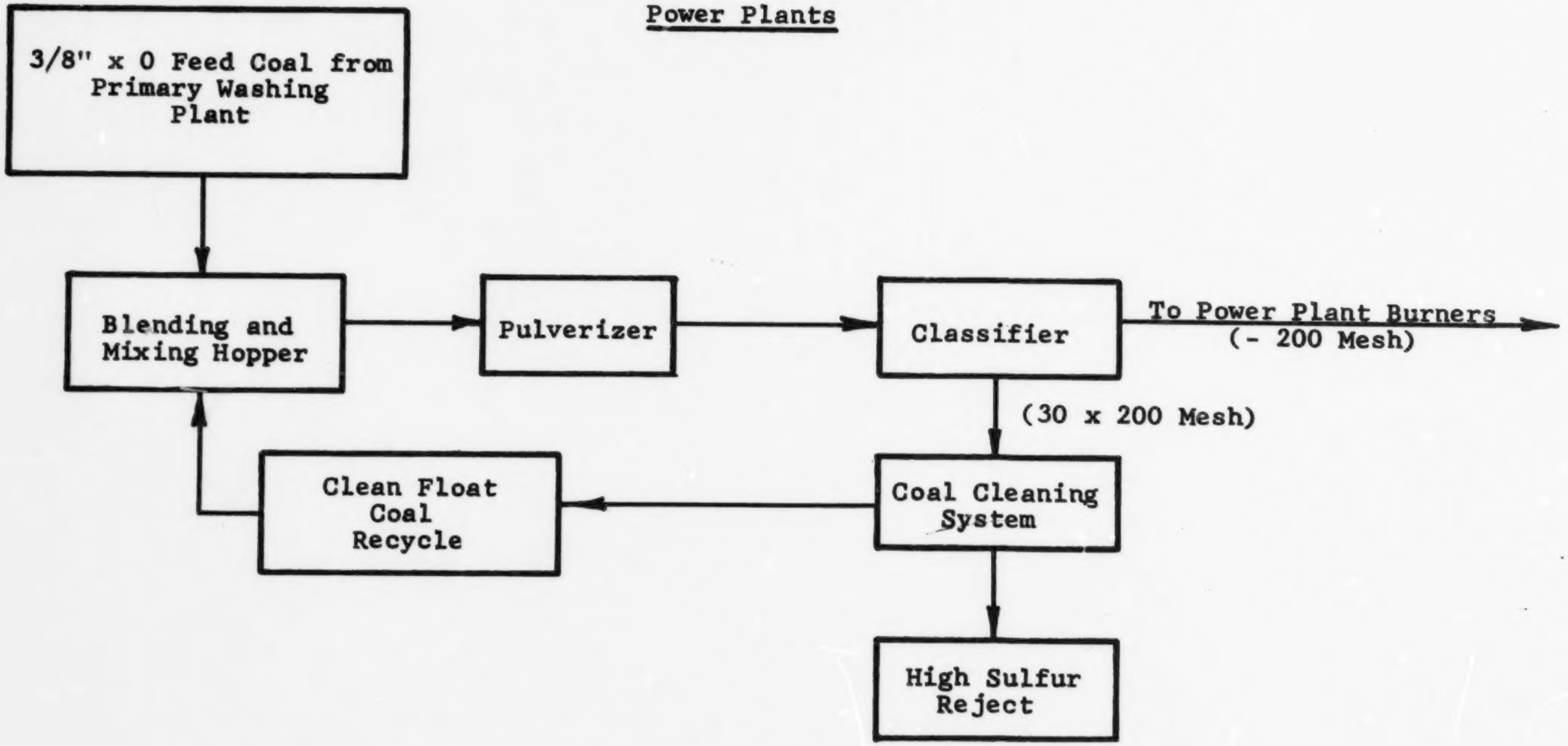
They have suggested that since coal in pulverized fuel type power plants has to be pulverized to a fine size, a pyrite concentration step be undertaken at the power plant. This is to be accomplished as shown in Figure No. 41. The coal is pulverized and sent through high efficiency air classifiers. Here the coarser particles, presumably 250-70 microns containing a high proportion of pyrite, are separated out and the minus 70 micron coal is fed directly to the boilers.

They propose that this coarse fraction, high in pyrite, be further treated by some standard coal cleaning device and the pyrite removed. The clean 250-70 micron coal would then be returned back to the pulverizer-air classifier circuit.

They conclude that two or more stages would be necessary and that some 50 percent of the coal would have to be re-cycled. They suggest that the original coal feed be washed first at a specific gravity of 1.60 in a standard coal preparation plant. The feasibility of this procedure is elaborated on later in this report (Section 5.4).

Figure 41

Removal of Pyrite by Pulverization, Classification and Wet Concentration at Power Plants


3/8" x 0 Feed Coal from Primary Washing Plant
Blending and Mixing Hopper
Pulverizer
Classifier
To Power Plant Burners
(- 200 Mesh)
(30 x 200 Mesh)
Coal Cleaning System
Clean Float Coal Recycle
High Sulfur Reject

Reference:
Bituminous Coal Research, Inc.
Paper by R. D. Harris
"Reducing Sulfur Content of Steam Coal"
SME, October 7-9, 1965

5.3 Experimental Wet Method of Removing Pyrite

The United States Steel Corporation at their Robena preparation plant has installed a pilot plant treating approximately 100 tons per hour of Pittsburgh bed coal for lowering the sulfur content to meet more stringent metallurgical coke requirements. They make a first separation of the coarse coal in a heavy media vessel, crush the coal to minus 1/4 inch and then hydroclassify the 1/4" x 0 into size fractions for further treatment on Deister tables, hydrocyclones and froth flotation. Their flow sheet is shown in Figure No. 42.

Robena is situated in Greene County, Pennsylvania. The total sulfur content in the raw run-of-mine may reach 2.50 percent of which organic sulfur varies from 0.90 to 1.00 percent.

The coal is first crushed to 3 inches and the 3" x 0 is wet screened at 1/4 inches. The 3" x 1/4" is cleaned in a heavy media vessel at a 1.55 separating density. The yield of coal from this stage is about 85 percent. Reject is discarded. This is part of the regular preparation plant. The 3" x 1/4" float coal is then crushed to minus 1/4 inches and combined with the previously screened raw minus 1/4 inches. The combined 1/4" x 0 is fed to a Deister, Concenco "Super-Sorter", multiple spigot hydraulic classifier.

This classifier has eight spigots and a rated feed capacity of 100 tons per hour. The discharge from the first spigot is high in rock and pyrite and goes directly to waste. The second spigot is considered middlings. The remaining spigots are fed to Deister tables, with one spigot feeding each Deister table.

The overflow from the hydroclassifier is mostly minus 28 mesh and water. This is fed to six 2-stage hydrocyclones, with the underflow of each to additional Deister tables. The cyclone overflow is cleaned by froth flotation.

The cleaned coal product is dewatered in a steam jacketed Dorr horizontal filter and the froth concentrates in a steam jacketed vacuum filter.

The sulfur content of the feed to the hydraulic classifier varies from 1.75 to 2.00 percent. The final sulfur in the combined product is about 1.40 percent.

It should be emphasized that this pilot plant is experimental and that further research is being conducted to improve and simplify the circuit.

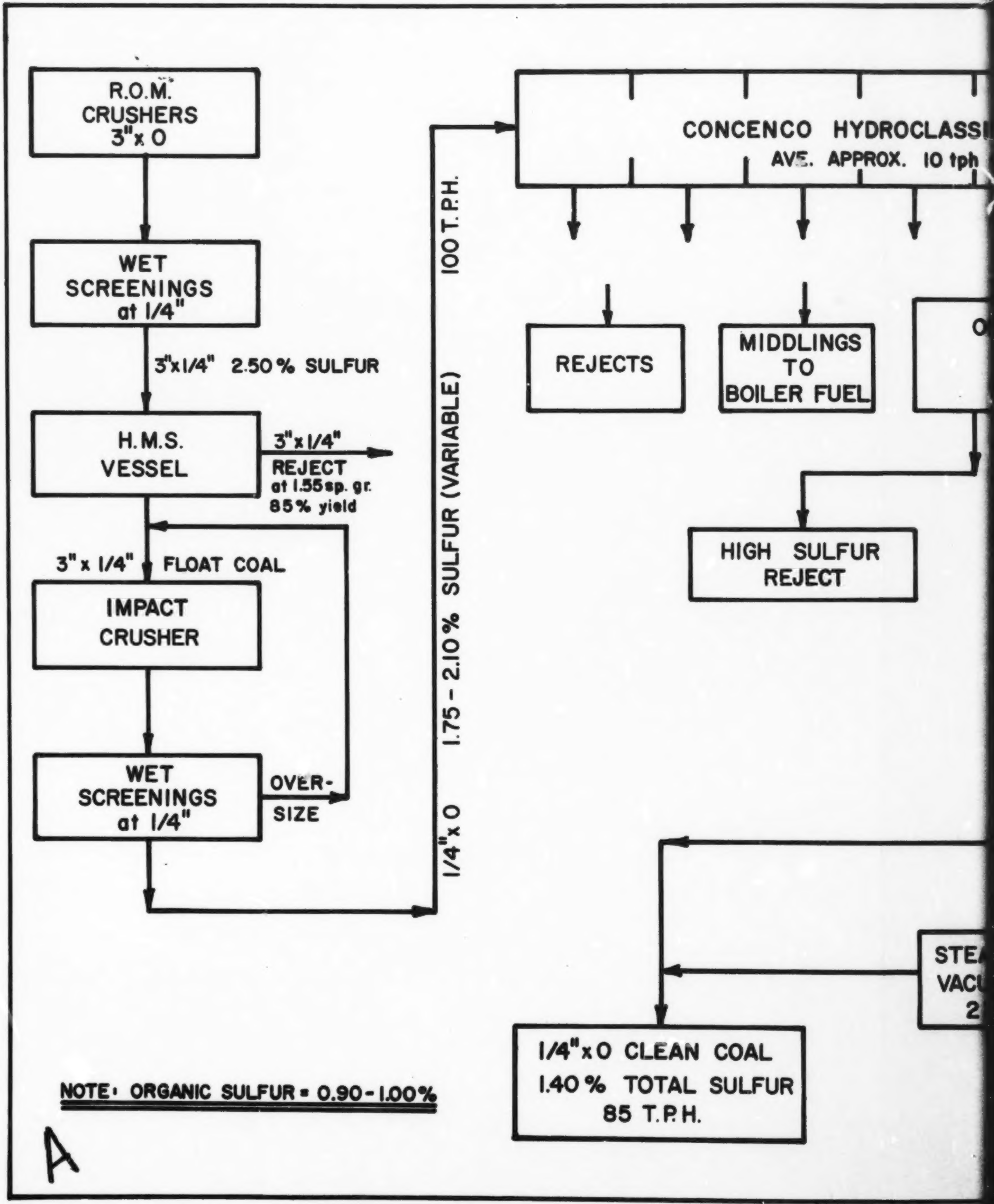
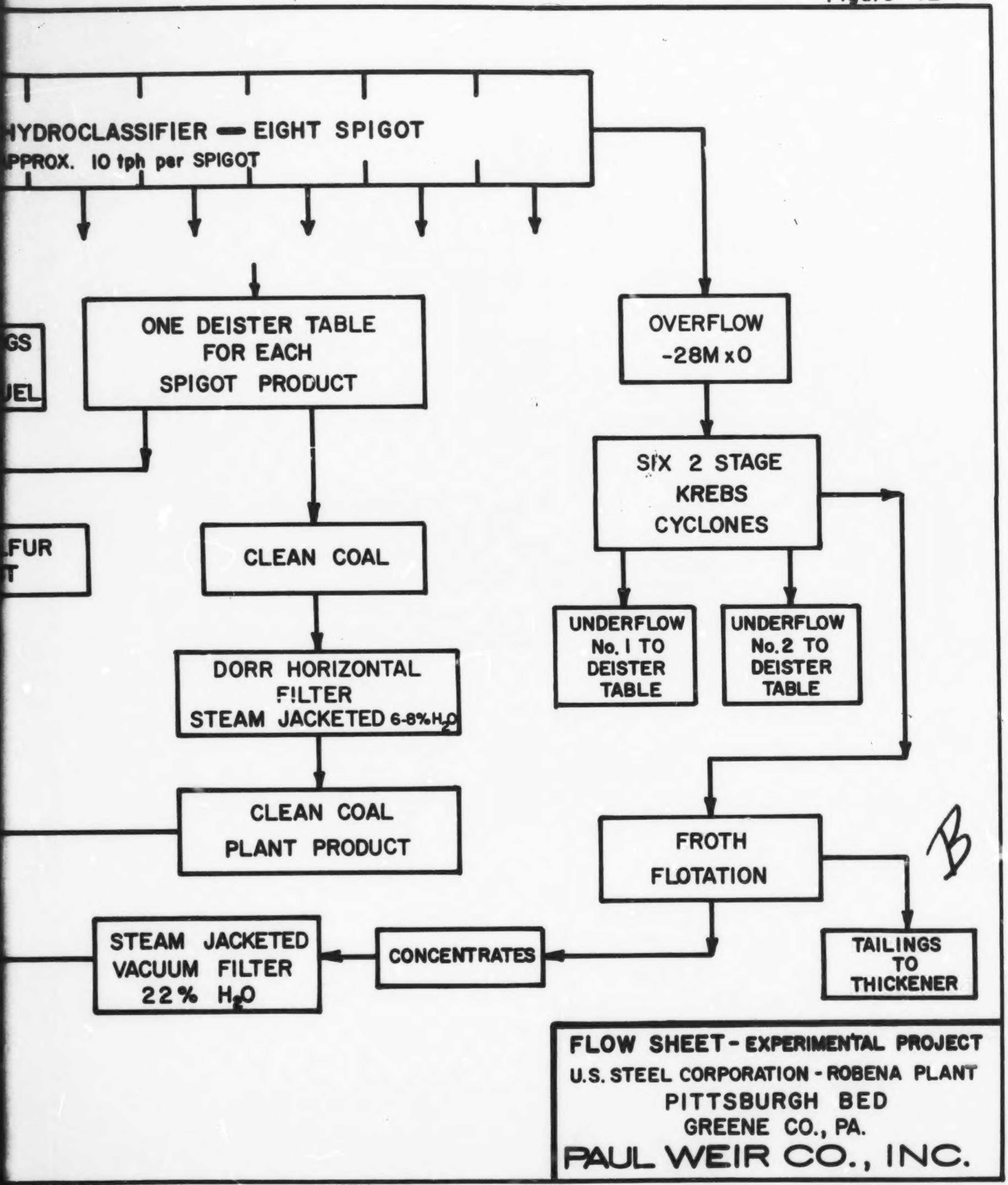

R.O.M. CRUSHERS 3"x 0
WET SCREENINGS at 1/4"
3"x1/4" 2.50 % SULFUR
H. M. S. VESSEL
3"x 1/4" REJECT at 1.55 sp. gr. 85 % yield
3" x 1/4" FLOAT COAL
IMPACT CRUSHER
WET SCREENINGS at 1/4"
OVER-SIZE
1/4"x 0 1.75 - 2.10 % SULFUR (VARIABLE) 100 T. P. H.
CONCENCO HYDROCLASSI
AVE. APPROX. 10 tph
REJECTS
MIDDLINGS TO BOILER FUEL
O
HIGH SULFUR REJECT
STE
VACU
2
1/4"x 0 CLEAN COAL 1.40 % TOTAL SULFUR 85 T. P. H.
NOTE: ORGANIC SULFUR = 0.90 - 1.00%
A

Figure 42


HYDROCLASSIFIER — EIGHT SPIGOT
PPROX. 10 tph per SPIGOT
GS
UEL
ONE DEISTER TABLE FOR EACH SPIGOT PRODUCT
LFUR
T
CLEAN COAL
DORR HORIZONTAL FILTER STEAM JACKETED 6-8% H_2O
CLEAN COAL PLANT PRODUCT
STEAM JACKETED VACUUM FILTER 22% H_2O
CONCENTRATES
OVERFLOW -28M x 0
SIX 2 STAGE KREBS CYCLONES
UNDERFLOW No. 1 TO DEISTER TABLE
UNDERFLOW No. 2 TO DEISTER TABLE
FROTH FLOTATION
B
TAILINGS TO THICKENER
FLOW SHEET - EXPERIMENTAL PROJECT
U.S. STEEL CORPORATION - ROBENA PLANT
PITTSBURGH BED
GREENE CO., PA.
PAUL WEIR CO., INC.

5.4 Some Proposed Methods of Desulfurization of Coal Based Upon Final Product Handling

In an attempt to combine the best available processes in current coal preparation technology at what might be considered a reasonable cost to produce low sulfur steam coal, three plans are submitted based primarily on the characteristics of the coal produced in regards to final particle size and the method of transporting this product. See Figure No. 43.

The limitation on particle size depends upon the manner in which the coal is transported to the power plant. It is generally conceived to be impractical to transport extremely fine coal in open type railroad cars. Therefore, one of the plans ("A") crushes the coal to a minus 3/8 inches. This could possibly be reduced to minus 1/4 inches, but at the expense of wind loss and storage problems at the power plant end.

Plan "B" goes to the ultimate in fine grinding, but assumes that this final grinding stage is at the power plant located in the vicinity of the coal preparation plant.

Plan "C" ends up with a 14 mesh x 0 size product in slurry form which can be pumped long distances through pipelines, or can be pumped to an adjacent power plant and burned wet in cyclone type burners.

In order to keep costs per ton of product down, a large tonnage plant is envisioned. The minimum feed rate should be about 1,000 tons per hour of raw coal and treating possibly over 3,000,000 tons of coal annually. The plant should be as thoroughly automated as possible to keep operating costs at a low level.

Plan "B" is an attempt to apply the Bituminous Coal Research, Inc. research on using fine grinding and air classifiers, as previously described. Plan "C" takes advantage of the successful pipeline operation by Consolidation Coal Company and their experiments in burning 50 percent solids coal slurry in cyclone furnaces without further dewatering.

Estimated capital and operating costs are given for each plan but it is readily admitted that these would vary with local conditions and the type of coal treated. The capital cost and operation of Plan "B", where it calls for classifiers between power plant pulverizers and the burners, may be in considerable error. Certainly, this would have to be thoroughly investigated as to both cost and practicability.

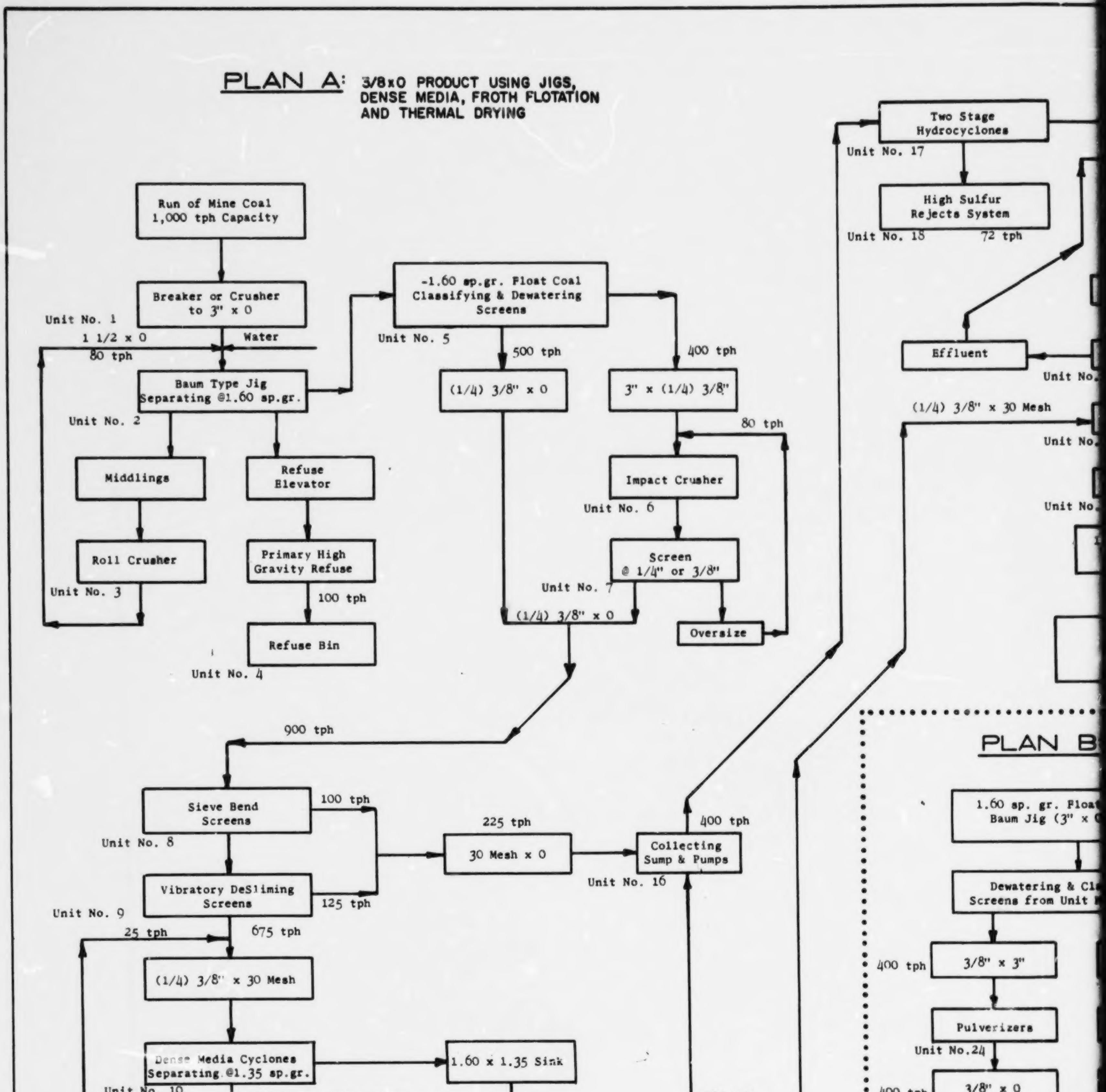
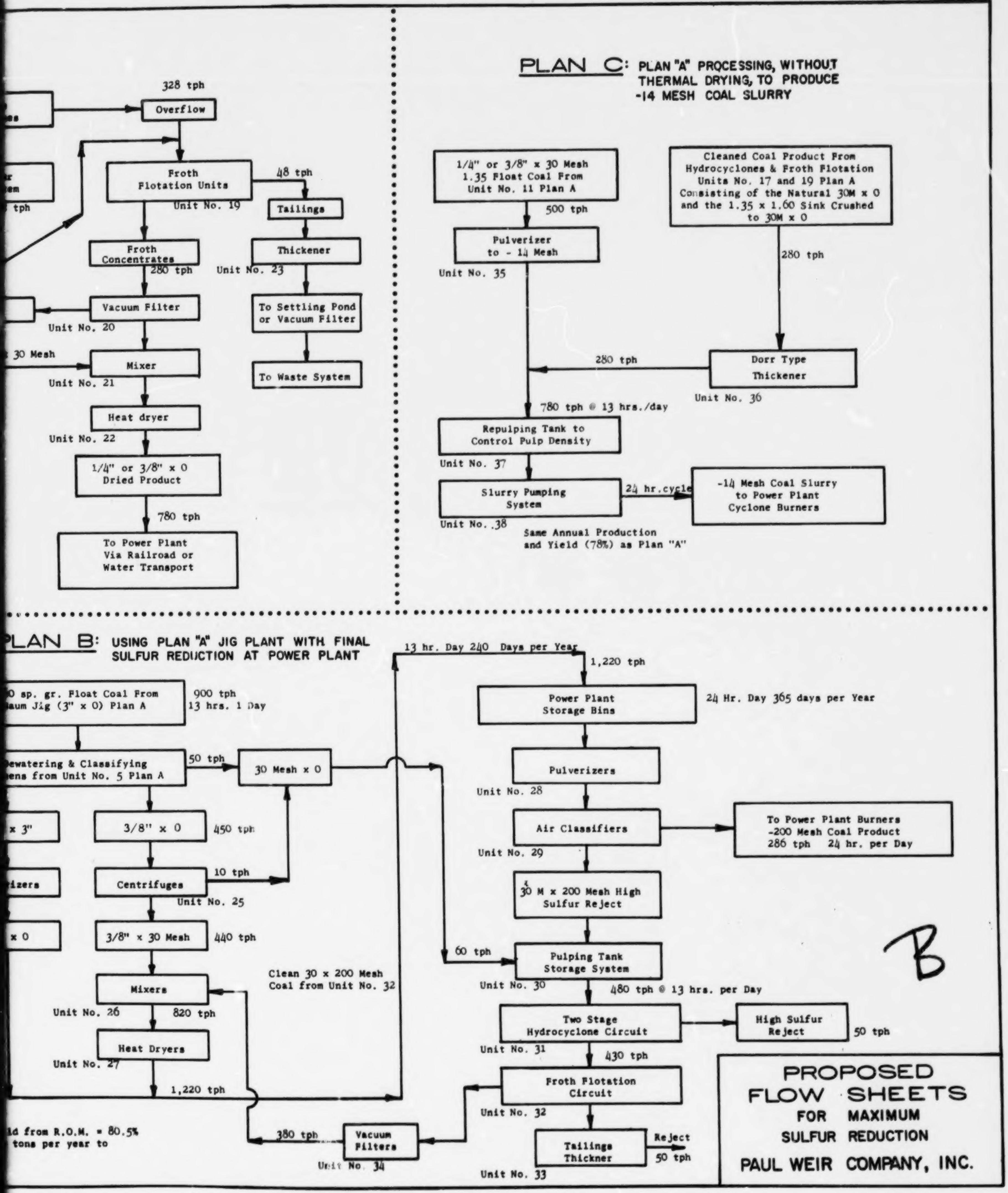

PLAN A: 3/8x0 PRODUCT USING JIGS, DENSE MEDIA, FROTH FLOTATION AND THERMAL DRYING
Run of Mine Coal 1,000 tph Capacity
Breaker or Crusher to 3" x 0
Unit No. 1
1 1/2 x 0
80 tph
Water
Baum Type Jig Separating @1.60 sp.gr.
Unit No. 2
Middlings
Refuse Elevator
Roll Crusher
Unit No. 3
Primary High Gravity Refuse
100 tph
Refuse Bin
Unit No. 4
-1.60 sp.gr. Float Coal Classifying & Dewatering Screens
Unit No. 5
500 tph
400 tph
(1/4) 3/8" x 0
3" x (1/4) 3/8"
80 tph
Impact Crusher
Unit No. 6
Screen @ 1/4" or 3/8"
Unit No. 7
(1/4) 3/8" x 0
Oversize
900 tph
Sieve Bend Screens
Unit No. 8
100 tph
225 tph
30 Mesh x 0
400 tph
Collecting Sump & Pumps
Unit No. 16
Vibratory DeSliming Screens
Unit No. 9
125 tph
25 tph
675 tph
(1/4) 3/8" x 30 Mesh
Dense Media Cyclones Separating @1.35 sp.gr.
Unit No. 10
1.60 x 1.35 Sink
1.35 Sp.Gr. Float Coal
175 tph
Drain & Rinse Screens
Unit No. 11
Sieve Bends & Drain & Rinse Screens
Unit No. 12
30 Mesh x 0 Classifier
Unit No. 15
Oversize
Centrifugal Dryers
Unit No. 13
Wet Grinding Mills
Unit No. 14
Effluent
(1/4) 3/8" x 30 Mesh
500 tph
A
Two Stage Hydrocyclones
Unit No. 17
High Sulfur Rejects System
Unit No. 18
72 tph
Effluent
Unit No.
(1/4) 3/8" x 30 Mesh
Unit No.
Unit No.
PLAN B
1.60 sp. gr. Float
Baum Jig (3" x
Dewatering & Cl
Screens from Unit
400 tph
3/8" x 3"
Pulverizers
Unit No.24
400 tph
3/8" x 0
Unit No
Unit No
Estimate Yield from R.O.M.
or 2,500,000 tons per year
Power Plant

Figure 43


PLAN C: PLAN "A" PROCESSING, WITHOUT THERMAL DRYING, TO PRODUCE -14 MESH COAL SLURRY
1/4" or 3/8" x 30 Mesh 1.35 Float Coal From Unit No. 11 Plan A
500 tph
Pulverizer to - 14 Mesh
Unit No. 35
Cleaned Coal Product From Hydrocyclones & Froth Flotation Units No. 17 and 19 Plan A Consisting of the Natural 30M x 0 and the 1.35 x 1.60 Sink Crushed to 30M x 0
280 tph
Dorr Type Thickener
Unit No. 36
280 tph
780 tph @ 13 hrs./day
Repulping Tank to Control Pulp Density
Unit No. 37
Slurry Pumping System
Unit No. 38
24 hr.cycle
-14 Mesh Coal Slurry to Power Plant Cyclone Burners
Same Annual Production and Yield (78%) as Plan "A"
328 tph
es
Overflow
r
em
tph
Froth Flotation Units
Unit No. 19
48 tph
Tailings
Froth Concentrates
280 tph
Thickener
Unit No. 23
Vacuum Filter
Unit No. 20
To Settling Pond or Vacuum Filter
30 Mesh
Mixer
Unit No. 21
To Waste System
Heat dryer
Unit No. 22
1/4" or 3/8" x 0 Dried Product
780 tph
To Power Plant Via Railroad or Water Transport
PLAN B: USING PLAN "A" JIG PLANT WITH FINAL SULFUR REDUCTION AT POWER PLANT
0 sp. gr. Float Coal From aum Jig (3" x 0) Plan A
900 tph 13 hrs. 1 Day
ewatering & Classifying ens from Unit No. 5 Plan A
50 tph
30 Mesh x 0
x 3"
3/8" x 0
450 tph
izers
Centrifuges
Unit No. 25
10 tph
x 0
3/8" x 30 Mesh
440 tph
Mixers
Unit No. 26
820 tph
Clean 30 x 200 Mesh Coal from Unit No. 32
Heat Dryers
Unit No. 27
1,220 tph
ld from R.O.M. = 80.5%
tons per year to
380 tph
Vacuum Filters
Unit No. 34
13 hr. Day 240 Days per Year
1,220 tph
Power Plant Storage Bins
24 Hr. Day 365 days per Year
Pulverizers
Unit No. 28
Air Classifiers
Unit No. 29
To Power Plant Burners -200 Mesh Coal Product 286 tph 24 hr. per Day
30 M x 200 Mesh High Sulfur Reject
60 tph
Pulping Tank Storage System
Unit No. 30
480 tph @ 13 hrs. per Day
Two Stage Hydrocyclone Circuit
Unit No. 31
High Sulfur Reject
50 tph
430 tph
Froth Flotation Circuit
Unit No. 32
Tailings Thickner
Unit No. 33
Reject 50 tph
B

PROPOSED FLOW SHEETS FOR MAXIMUM SULFUR REDUCTION

PAUL WEIR COMPANY, INC.

The tonnage distribution and yield figures shown in the various plans will depend upon the washability characteristics of the coal treated. The tonnages given in Plans "A", "B" and "C" are based upon yields from the Illinois No. 6 bed where the initial yield at 1.60 specific gravity is 90 percent, and there is only a moderate amount of near gravity material and high ash reject.

For comparable results one could take the Pennsylvania coals shown in Table No. 7, showing the effect of crushing down to 14 mesh, or the results shown in Table No. 8, where the Pittsburgh bed coal is pulverized to 200 mesh, or Table No. 9, the Ohio Meigs Creek bed, showing the effect of crushing down to 30 mesh. Some results are shown in Table No. 23.

Only in Plan "B" is all the coal crushed to 30 mesh and finer, however, the middling fraction of the coals in Plans "A" and "C" are ground to minus 30 mesh.

It will be noticed that Plan "B" has a somewhat higher coal yield than either "A" or "C". This is based upon the fact that approximately half of the 1.60 float coal passes directly to the power plant burners through the classifiers and is not rewashed.

5.4.1 Plan "A" Description (Figure No. 43)

In Plan "A" the run-of-mine coal is crushed to 3" x 0 and washed at 1.60 separating density in Baum type jigs. A primary refuse is produced and discarded. A middling product is crushed to minus 1-1/2 inches and recirculated. The float coal from the jigs is dewatered and screened at 3/8 inches. The 3" x 3/8" is crushed to minus 3/8 inches.

The 1.60 float coal is now all minus 3/8" x 0. The minus 30 mesh is removed by use of sieve bends and desliming screens. The 3/8" x 30 mesh is recleaned in dense media cyclones at either 1.45 or 1.35 specific gravity. The reject from these cyclones is chiefly 1.60 x 1.45 or 1.35 middlings. This material is ground in wet grinding mills to minus 30 mesh.

The 30 mesh x 0 is all collected and passed first through two stage hydrocyclones to obtain a high sulfur reject and the coal further cleaned by froth flotation.

The 30 mesh x 0 coal is filtered and combined with the 3/8" x 30 mesh coal and thermally dried. It is ready for shipment by either railway, truck or water transport.

The capital cost of Plan "A" is shown in Table No. 21 and estimated at $5,600,000. Its operating costs are estimated as shown in Table No. 22. On $2.45 per ton run-of-mine coal, the final cost is estimated to be $3.628 per ton of product or 15.1 cents per million Btu for 12,000 Btu per pound coal.

5.4.2 Plan "B" Description (Figure No. 43)

Plan "B", utilizing the effect of final pulverization and classifying at the power plant, starts off similar to Plan "A", by cleaning 3" x 0 in Baum jigs. The 3" x 3/8" is crushed to 3/8" x 0 and sent to the power plant pulverizers. The air classifiers reject 50 percent as 30 x 200 mesh and is returned to the washery and combined with the natural 30 mesh x 0 coal. This combination is then cleaned in a hydrocyclone-froth flotation circuit, as in Plan "A" and its product combined with 1.60 specific gravity float 3/8" x 30 mesh coal and thermally dried. This dried 3/8" x 0 coal is then combined with the crushed 3" x 3/8" coal.

The capital cost of Plan "B" is shown in Table No. 21 and estimated at $6,300,000. Its operating costs are estimated as shown in Table No. 22. On $2.45 per ton run-of-mine coal, the final estimated cost is $3.675 per ton or 15.3 cents per million Btu for 12,000 Btu per pound coal. The higher operating cost than Plan "A" is the result of including additional operating costs at the power plant.

The additional costs at the power plant may actually be considerably higher than shown here.

5.4.3 Plan "C" Description (Figure No. 43)

Plan "C" is an attempt to incorporate a final production of coal slurry that can either be pumped to distant power plants or to a local power plant. The treatment of the coal starts off similar to Plan "A" and "B", by being first washed at 1.60 in Baum jigs, and the 3/8" x 30 mesh rewashed in dense media cyclones at 1.45 and 1.35.

The clean 3/8" x 30 mesh coal is then ground to minus 14 mesh. The middling (1.60 x 1.45 or 1.35) 3/8" x 30 mesh is pulverized to minus 30 mesh as in Plan "A", and treated by hydrocyclones and froth flotation.

The 30 mesh x 0 product is collected and thickened in a Dorr type thickener and combined with the crushed 14 mesh x 0 in a re-pulping tank for slurry pumping.

The capital cost of Plan "C" is shown in Table No. 21 and estimated as $5,100,000. This is exclusive, of course, of any long distance pumping installations. Its operating costs are estimated as shown in Table No. 22. On $2.45 per ton run-of-mine coal, the final estimated costs are $3.557 per ton product or 14.8 cents per million Btu for 12,000 Btu per pound coal. This is on a dry coal basis and not on a slurry basis.

Table No.21

Estimated Capital Costs of Preparation Plants for Maximum Sulfur Reduction

(All Plants Based Upon 1,000 T.P.H. ROM Capacity)

Plan "A" - A 3/8" x 0 product, using jigs, dense media, flotation and drying.

Raw coal handling and coarse coal crusher		
2 Baum jigs, with middlings crusher		
Primary dewatering screens, necessary pumps, electricals, building, etc.		
	Sub-Total	$2,000,000
Dense media (magnetite) cyclone fine coal cleaning circuit		1,100,000
1.35 x 1.60 sink grinding mills		100,000
30 mesh x 0, hydrocyclone, flotation, filtering and water circuits		1,700,000
Thermal dryers(2) complete with mixers, dust collection, etc.		700,000
	Total Plan "A"	$5,600,000

Plan "B" - (using final sulfur reduction at power plant classifiers)

Jig plant (as in Plan "A")		$2,000,000
30 mesh x 0, hydrocyclone, flotation, filtering, water circuits		1,800,000
Thermal dryers (2) complete with mixers, dust collectors, etc.		800,000
	Sub-Total	$4,600,000

Additional equipment required at power plant:

Air classifiers		$ 750,000
Additional pulverizers to handle re-circulation load		600,000
Additional storage and handling system		200,000
Thickeners and storage system for 30 x 200 mesh pulp		150,000
	Sub-Total	$1,700,000
	Total Plan "B"	$6,300,000

Plan "C" - (slurry to pipeline or direct to power plant)

Plan "A" equipment, including Jig plant Dense media cyclone circuit Middling (cyclone sink) grinding mills 30 mesh x 0, hydrocyclone and froth flotation circuit	$4,900,000
Pulverizing 3/8" x 30 mesh to 14 mesh x 0	100,000
Sub-Total	$5,000,000
Storage and mixing tanks ahead of slurry pumping station	100,000
Total Plan "C"	$5,100,000

Slurry to be pumped as a 14 mesh x 0, 55 percent - 60 percent solids mixture suitable for long distance pipelining or direct to"mine mouth" power plant cyclone burners.

Note:

1. All above plans based upon main plant only and does not include Raw coal storage, unit train loading, railroad and other auxiliaries.

2. On the basis of two shifts operation per day, totalling 13 hours and 240 days per year:

   Run of Mine - 3,100,000 tons per year
   Clean Coal:
      Plan "A" - 2,400,000 tons per year
      Plan "B" - 2,500,000 tons per year
      Plan "C" - 2,400,000 tons per year

Table No. 22

Estimated Costs Per Ton Product for Plans "A", "B", "C", for Maximum Sulfur Reduction

Plan "A"

1.	Capital cost (1,000 t.p.h. run of mine) =	$5,600,000
	@ 2,400,000 tons product per year and 20 year life	$0.117 per ton product
2.	Direct Operating Costs:	
	Labor	$0.03/ton product
	Maintenance (labor)	0.04
	Supplies	0.16
	Power	0.11
	Refuse Handling	0.03
	Total	$0.37/ton product
3.	Mining Costs:	
	Run of Mine	$2.45/ton
	@ 78 percent yield	$3.141/ton product
4.	Total Costs, f.o.b.:	
		$0.117/ton product
		0.370
		3.141
	Total	$3.628/ton product
5.	At 12,000 Btu/lb. cost per million Btu, f.o.b. =	15.1 cents

Plan "B"

1.	Capital Cost (1,000 t.p.h. run of mine) $4,600,000 plant + $1,700,000 additional power plant equipment, total =	$6,300,000
	@ 2,500,000 tons product per year and 20 year life	$0.142/ton product
2.	Direct Operating Costs:	
	Labor	$0.04/ton product
	Maintenance (Labor)	0.05
	Supplies	0.18
	Power	0.19
	Refuse Handling	0.03
	Total	$0.49/ton product

Plan "B" (continued)

3. Mining Costs:	
Run of Mine	$2.45/ton
@ 80.5 percent yield	$3.043/ton product
4. Total Costs, f.o.b.:	$0.142
	0.490
	3.043
Total	$3.675/ton product
5. At 12,000 Btu/lb. cost per million Btu, f.o.b. =	15.3 cents

Plan "C"

1. Capital Cost (1,000 t.p.h. run of mine) =	$5,100,000
@ 2,400,000 tons product per year and 20 year life	$0.106/ton product
2. Direct Operating Costs:	
Labor	$0.03/ton product
Maintenance (Labor)	0.04
Supplies	0.11
Power	0.10
Refuse Handling	0.03
Total	$0.31/ton product
3. Mining Costs:	
Run of Mine	$2.45/ton
@ 78 percent yield	$3.141/ton product
4. Total Costs, f.o.b.:	
	$0.106/ton product
	0.310
	3.141
Total	$3.557/ton product
5. At 12,000 Btu/lb. cost per million Btu, f.o.b. =	14.8 cents

Table No. 23

Estimated Results of Sulfur Levels Using Either Plan "A", "B" or "C"

Coal Bed	Location	1.45 - 1.50 Specific Gravity 3/8" x 0	1.45 - 1.50 Specific Gravity 14 Mesh x 0	Head Sulfur Raw Coal
Upper Kittanning	Pennsylvania	1.27	0.90	3.76
Lower Kittanning	"	0.93	0.82	3.38
Middle Kittanning	"	1.57	-	5.64
Upper Freeport	"	1.23	1.03	2.62
Lower Freeport	"	1.61	1.34	3.29
Brookville	"	2.19	1.76	2.62
Clarion	"	2.01	1.81	4.57
Pittsburgh	"	1.42	1.35	2.27
Meigs Creek # 9	Ohio	-	2.93 (1)	4.79
Pittsburgh	West Virginia	3.35	2.75 (2)	4.14
Pittsburgh #8	Ohio	1.85	-	2.90

(1) Coal crushed to minus 30 mesh.

(2) This coal crushed to 200 mesh indicates a sulfur reduction to 1.90 % at 1.45 specific gravity.

Refer to Table No. 6 for possible sulfur reduction in other beds. Data on fine grinding is incomplete. Also pyritic distribution in coal beds will vary considerably from one area to another.

5.5 Possible Recovery of Iron and Sulfur As a By-product in Coal Desulfurization

Although it is not part of this feasibility report on coal desulfurization, it is felt that some mention should be made as to the possibility of recovering pyrite from the coal in sufficient concentrations to make it economically worthwhile to ship pyrite as such to chemical plants or to perhaps install a central iron and sulfur recovery plant that could utilize pyrite obtained from coal refuse.

Utilizing any of the proposed Plans "A", "B" or "C", previously discussed in Section 5.4, or any coal preparation plant where the refuse is high in pyritic content, it is possible to further concentrate the pyrite to a strength sufficient to be fed to various types of sulfuric acid producing processes, such as the lead chamber or contact methods, and by fluo solid roasting to sulfur dioxide gas and catalytic oxidation to sulfuric acid.

The amount of sulfur in some reject sizes from preparation plants may be as high as 20-25 percent or 40-50 percent FeS_2. The fine crushing of the coal will free a high percentage of any carbonaceous material from pyrite particles.

It is technically feasible to remove both recoverable iron as well as sulfur by proper processing. This is being accomplished in various parts of the world. An example of a method is shown in Figure No. 44. The major steps are shown in block diagram.

Impure pyrite is fed into a fluo solid desulfurization roaster. This is an exothermic reaction in which considerable waste heat could be utilized. Sulfur dioxide gas is driven off and passed through a catalytic reactor to produce sulfuric acid.

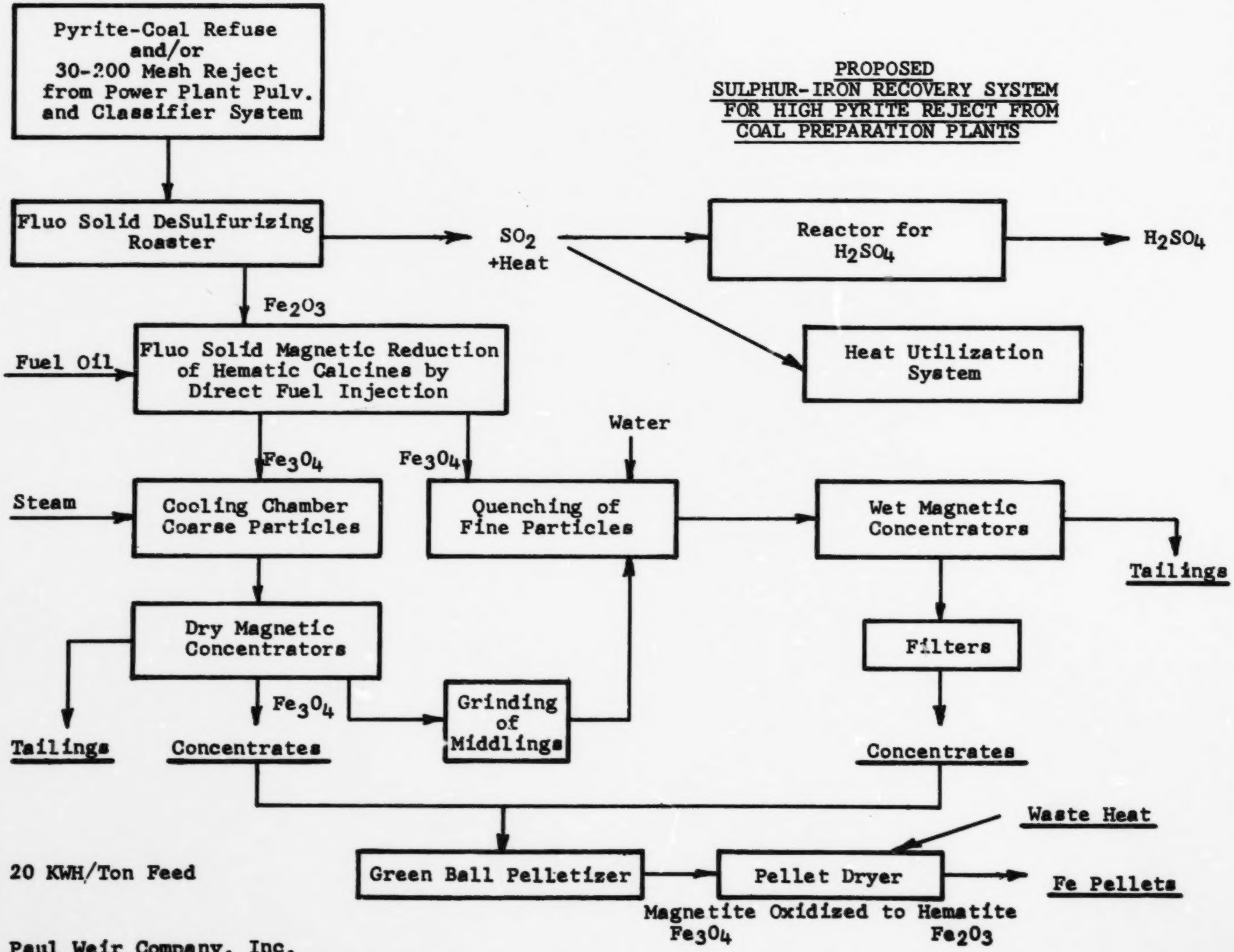
The solid discharge from the roaster is Fe_2O_3 calcines or hematite. These calcines are fed into a fluo solid reactor into which by direct injection of fuel oil a magnetic reduction takes place forming Fe_3O_4.

The coarse Fe_3O_4 is fed to a cooling chamber and then fed to dry magnetic concentrators. A tailings is produced, a high grade Fe_3O_4 concentrate and a middlings. This latter is crushed and added to the fines from the quencher and then the combination recovered by wet magnetic concentrators.

Both coarse and fines can then be pelletized and dried using waste heat from the roaster and a product of Fe_2O_3 pellets is produced, sulfur free.

It is believed that this method or other processes should be investigated to determine whether such a process or processes could be economically feasible and thus partly balance the extra cost of coal desulfurization.

Figure 44



PROPOSED
SULPHUR-IRON RECOVERY SYSTEM
FOR HIGH PYRITE REJECT FROM
COAL PREPARATION PLANTS

Pyrite-Coal Refuse and/or 30-200 Mesh Reject from Power Plant Pulv. and Classifier System
Fluo Solid DeSulfurizing Roaster
SO_2 +Heat
Reactor for H_2SO_4
H_2SO_4
Heat Utilization System
Fe_2O_3
Fuel Oil
Fluo Solid Magnetic Reduction of Hematic Calcines by Direct Fuel Injection
Fe_3O_4
Fe_3O_4
Water
Steam
Cooling Chamber Coarse Particles
Quenching of Fine Particles
Wet Magnetic Concentrators
Tailings
Dry Magnetic Concentrators
Filters
Fe_3O_4
Tailings
Concentrates
Grinding of Middlings
Concentrates
Waste Heat
Green Ball Pelletizer
Pellet Dryer
Fe Pellets
Magnetite Oxidized to Hematite
Fe_3O_4
Fe_2O_3

20 KWH/Ton Feed

Paul Weir Company, Inc.

SECTION 6.0 References

1. U.S. Bureau of Mines
    - (a) All Technical Papers dealing with Coal Preparation and Coal Analyses.
    - (b) All Information Circulars dealing with Coal Preparation and Coal Analyses.
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    - (e) Reports of Investigations.
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2. "Liberation of Pyrite from Steam Coals", by R. A. Glenn and R. D. Harris, Bituminous Coal Research, Inc., Monroeville, Pennsylvania, American Power Conference.

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11. Illinois Geological Survey, Urbana, Illinois

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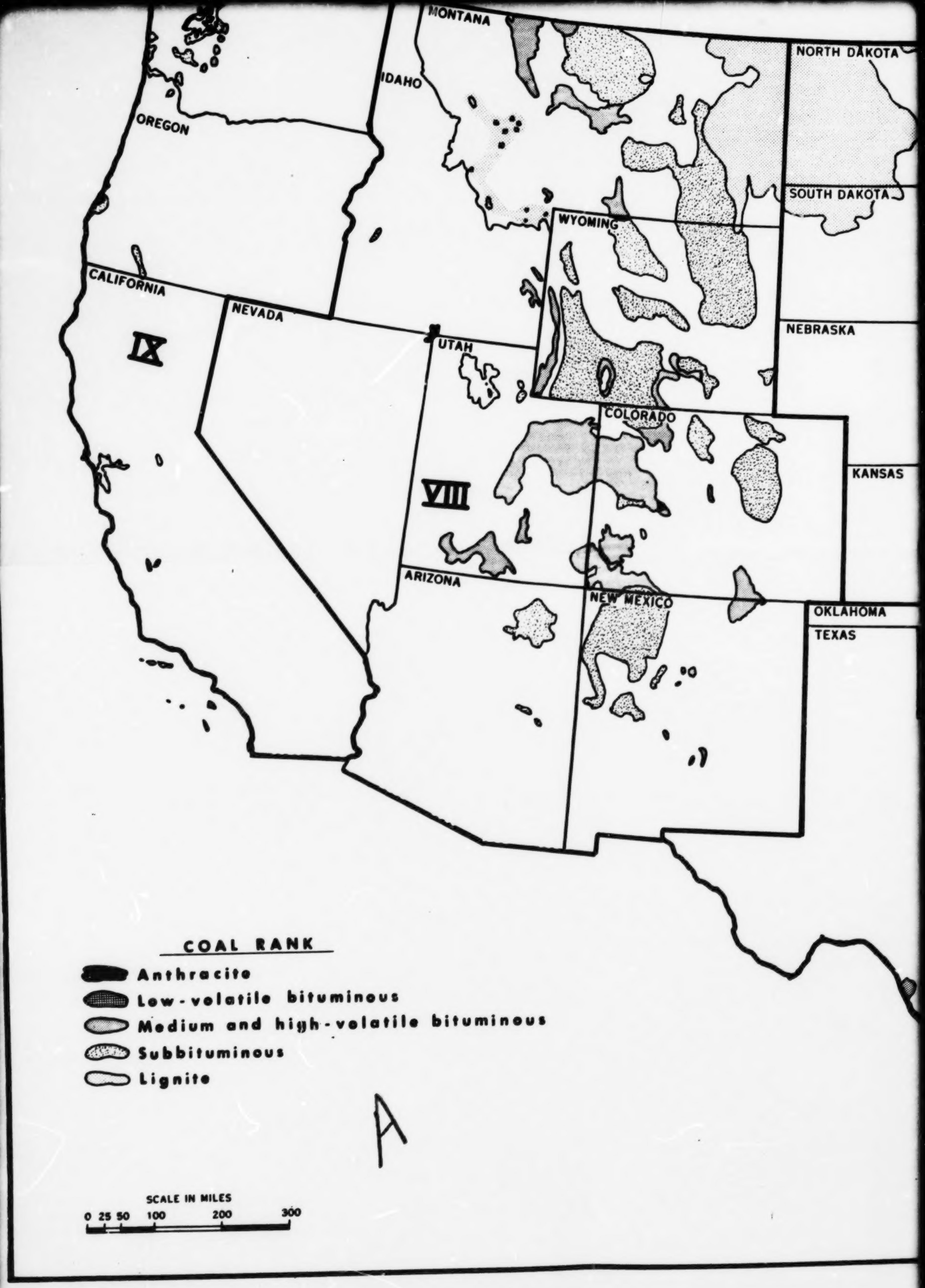
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COLORADO
KANSAS
VIII
ARIZONA
NEW MEXICO
OKLAHOMA
TEXAS
COAL RANK
Anthracite
Low-volatile bituminous
Medium and high-volatile bituminous
Subbituminous
Lignite
SCALE IN MILES
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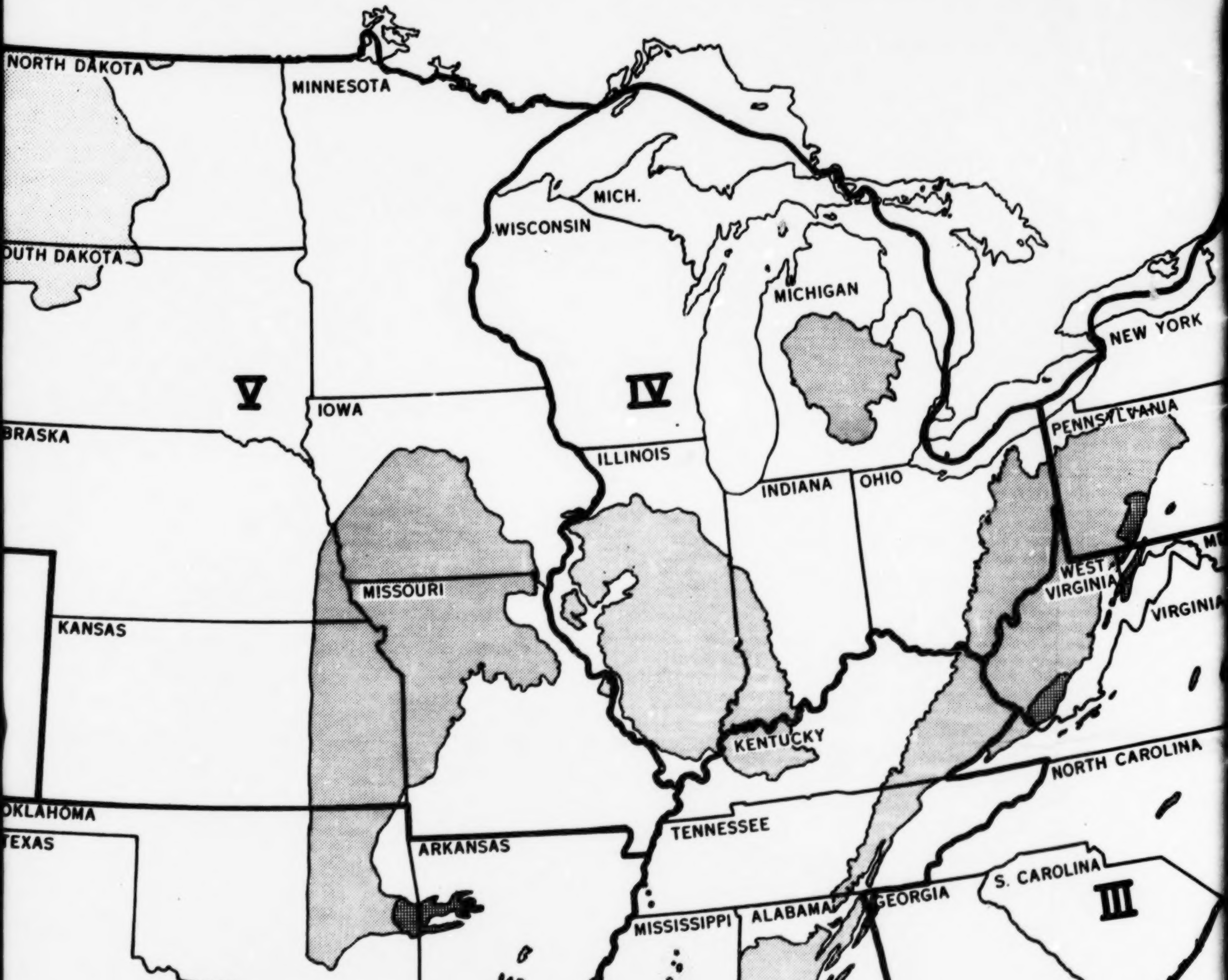
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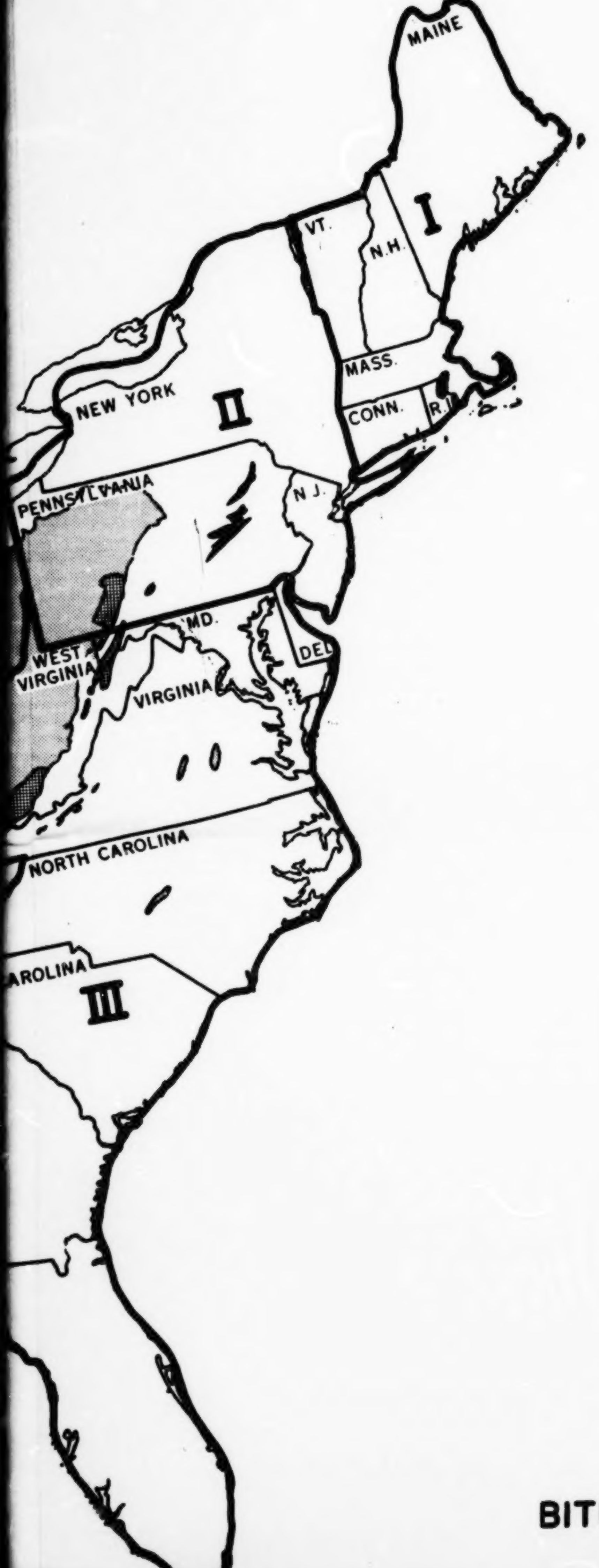
GEORGIA
LOUISIANA
VII
VI
FLORIDA

B

EXHIBIT A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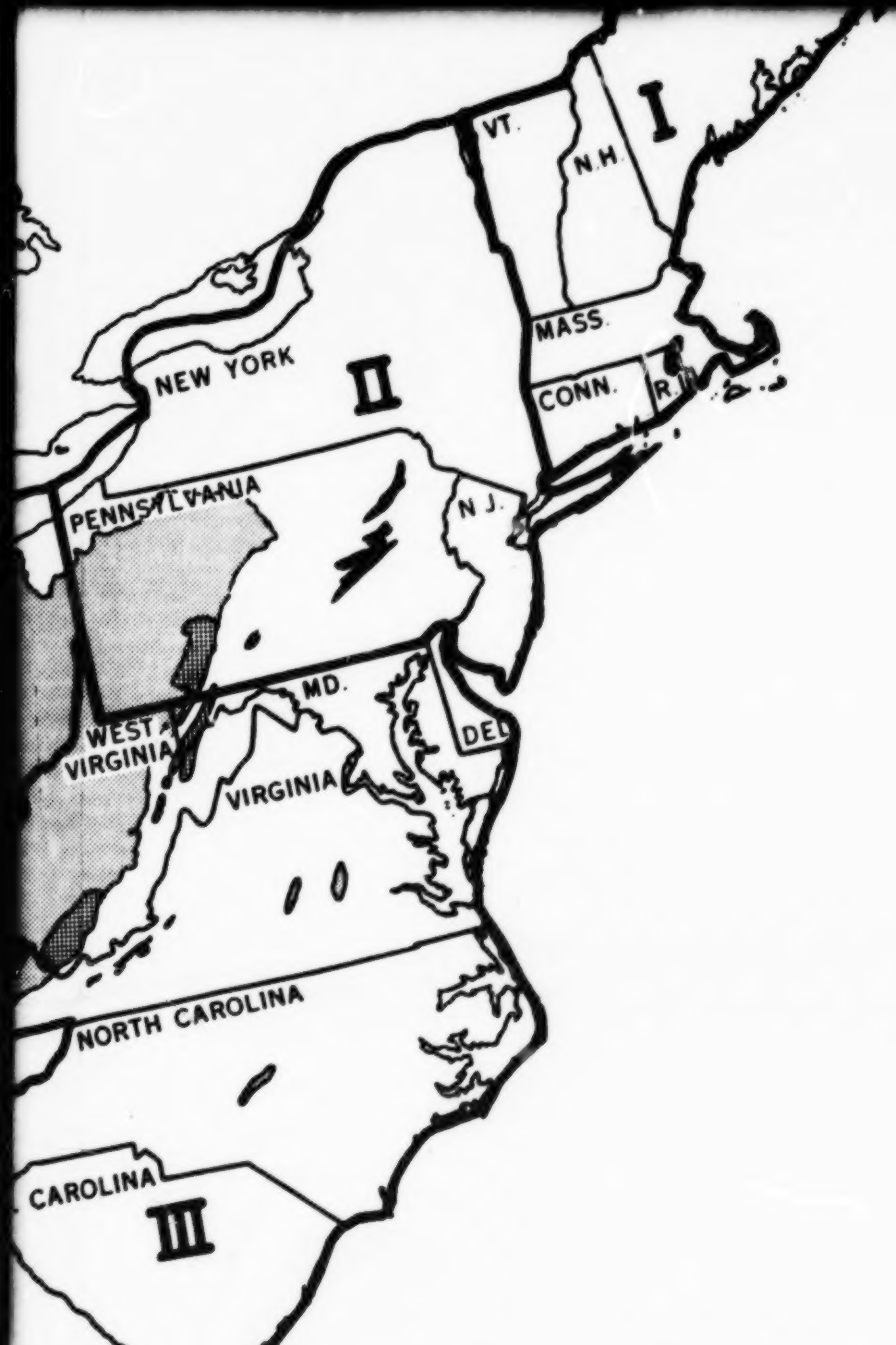
C

REGIONS of CONSUMPTION
of
BITUMINOUS COAL and LIGNITE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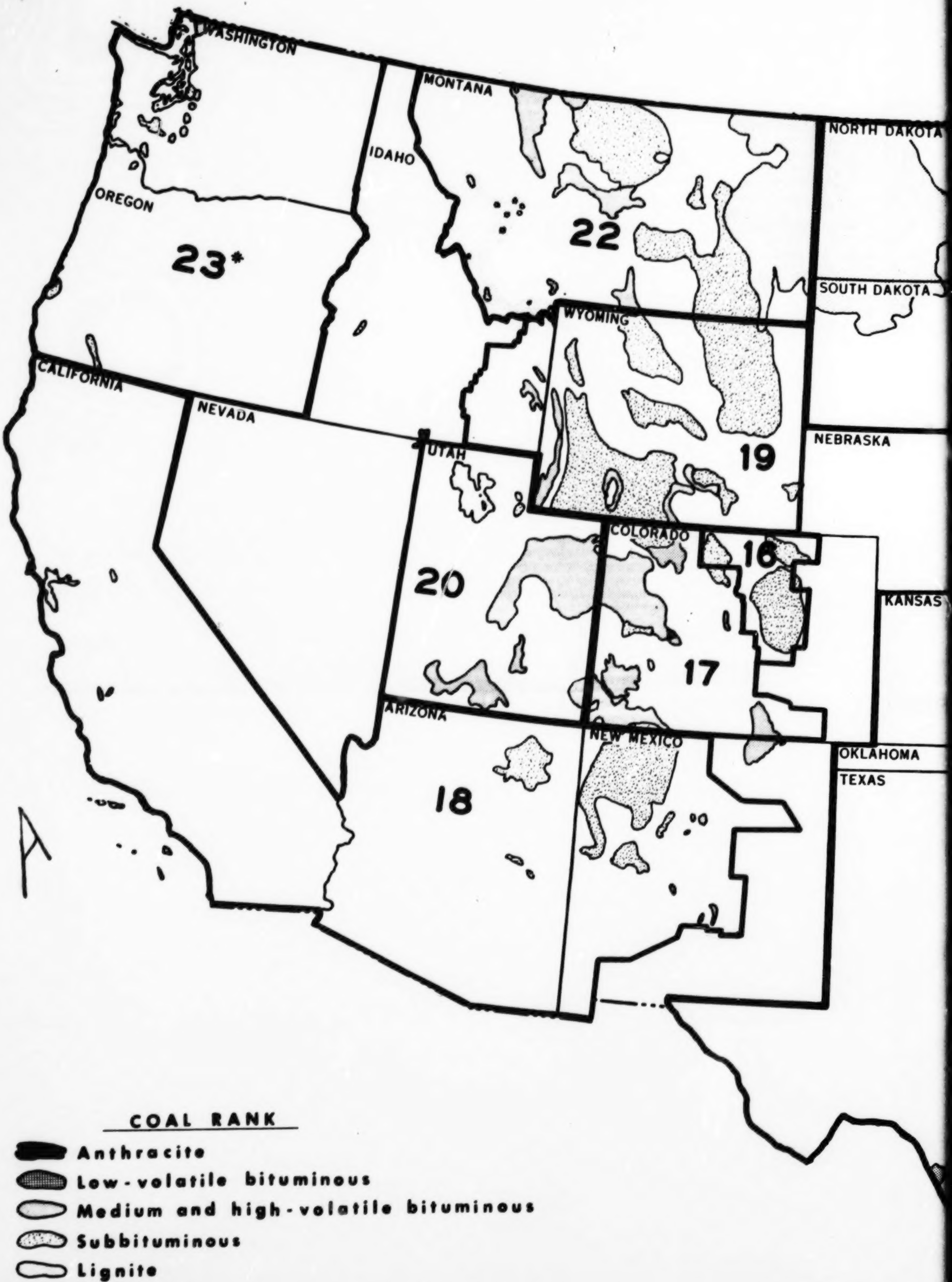
VIRGINIA
NORTH CAROLINA
CAROLINA
III

C

D

REGIONS of CONSUMPTION
of
BITUMINOUS COAL and LIGNITE

PAUL WEIR COMPANY
INCORPORATED
MINING ENGINEERS AND GEOLOGISTS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IDAHO
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22
23*
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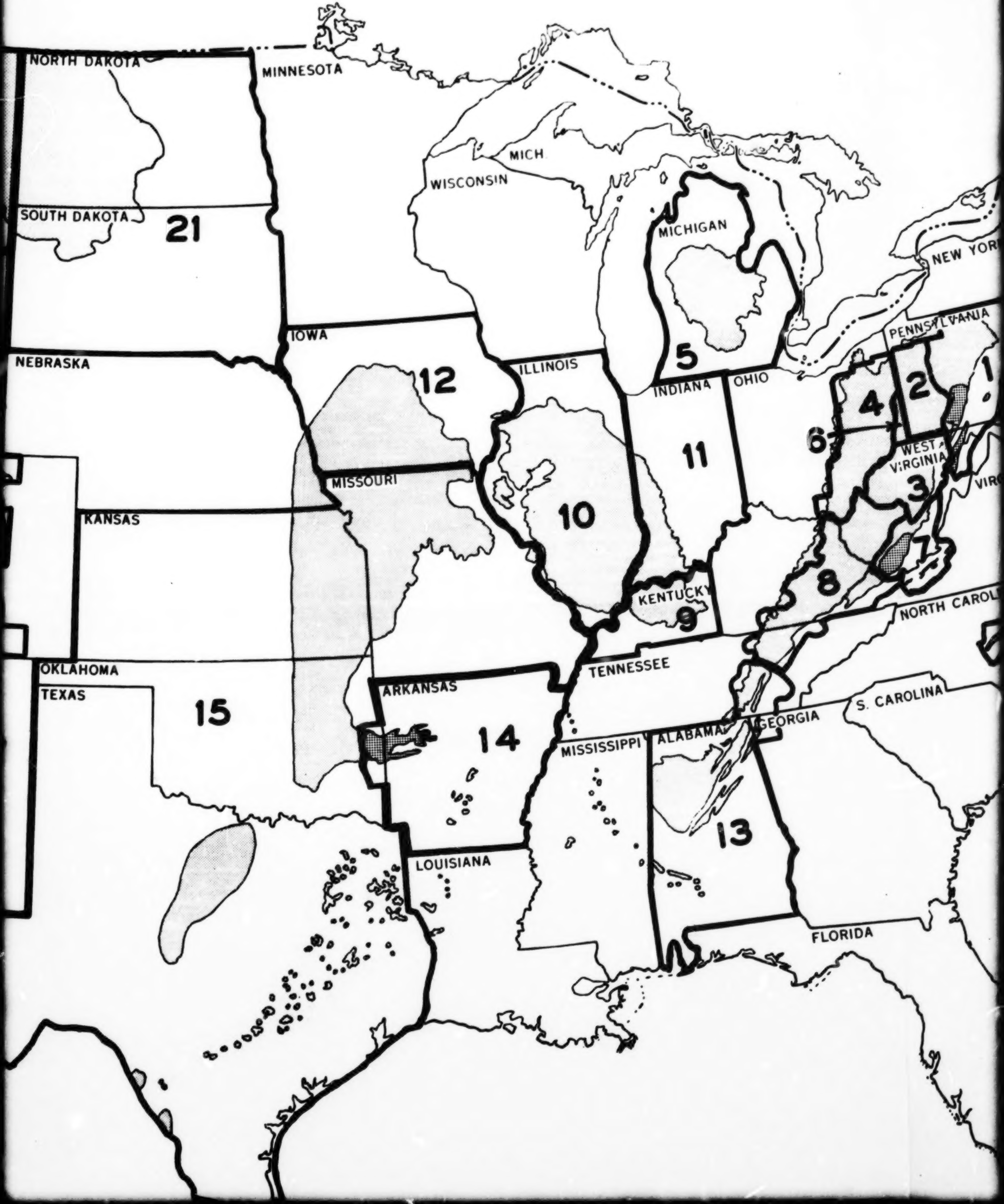
WYOMING
CALIFORNIA
NEVADA
NEBRASKA
19
UTAH
COLORADO
16
20
KANSAS
17
ARIZONA
NEW MEXICO
OKLAHOMA
TEXAS
18
COAL RANK
Anthracite
Low-volatile bituminous
Medium and high-volatile bituminous
Subbituminous
Lignite

B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MINNESOTA
MICH.
WISCONSIN
SOUTH DAKOTA
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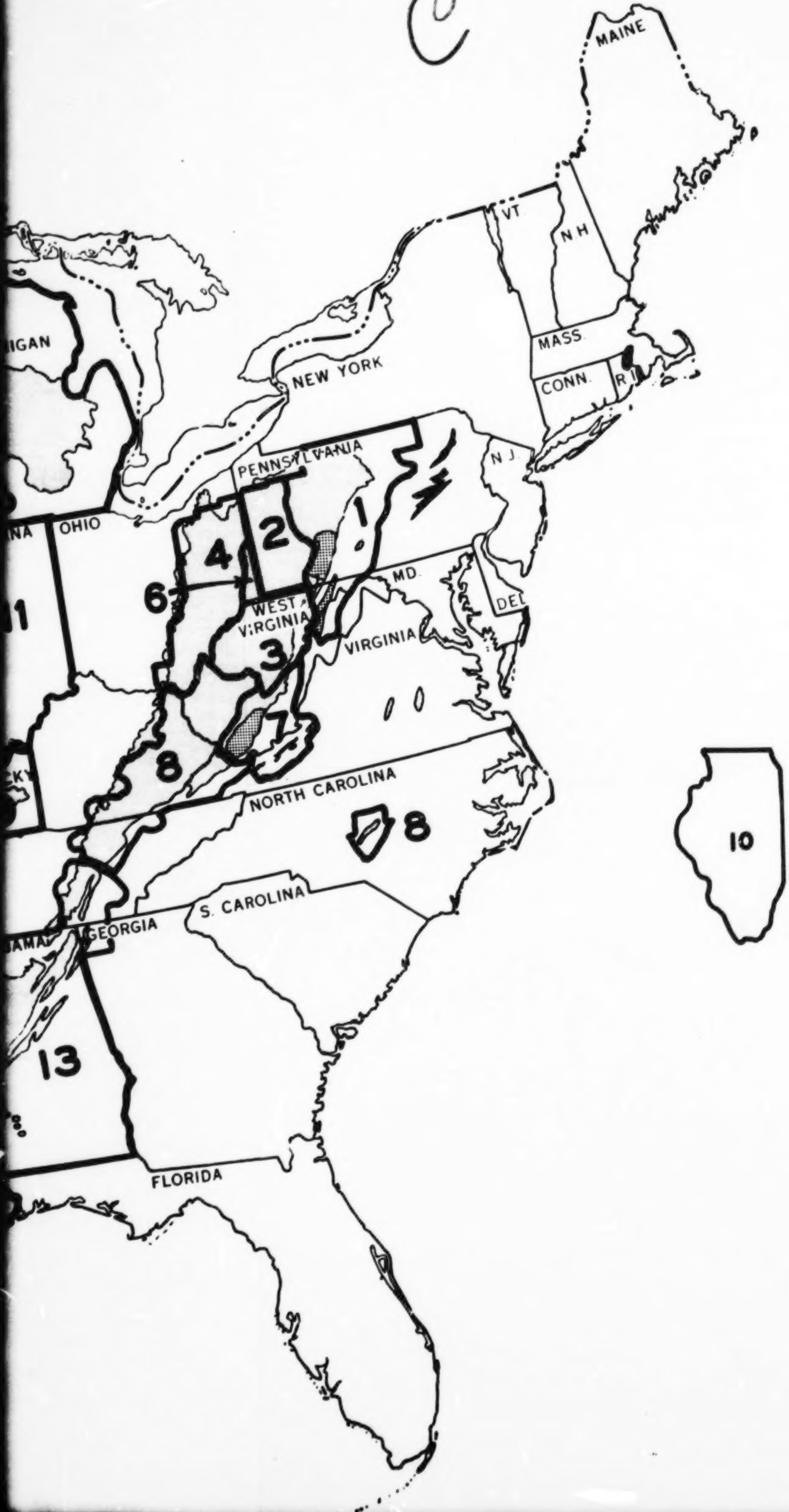
MICHIGAN
NEW YORK
PENNSYLVANIA
5
IOWA
NEBRASKA
12
ILLINOIS
INDIANA
OHIO
4
2
1
6
11
WEST VIRGINIA
MISSOURI
3
VIRG
KANSAS
10
7
8
KENTUCKY
9
NORTH CAROL
OKLAHOMA
TENNESSEE
TEXAS
ARKANSAS
15
S. CAROLINA
GEORGIA
ALABAMA
MISSISSIPPI
14
13
LOUISIANA
FLORIDA

E

C


MAINE
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VIRGINIA
NORTH CAROLINA
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S. CAROLINA
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CKY
13
FLORIDA
10

Bituminous coal produ
district.

*District 23 includes Alaska.

Note: See Exhibit C.

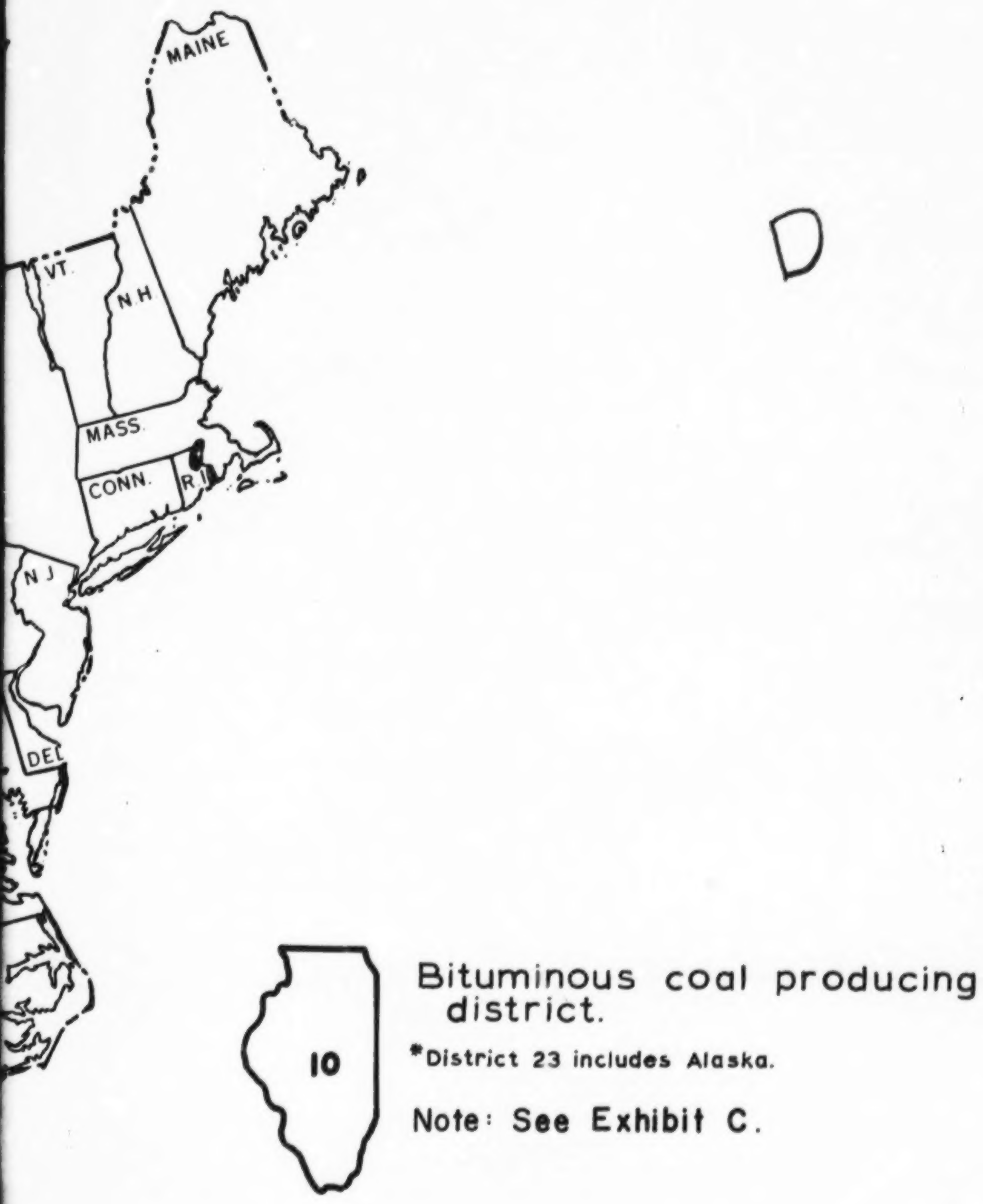
COAL FIELD

# of the

UNITED STAT

EXHIBIT B

D


MAINE
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MASS.
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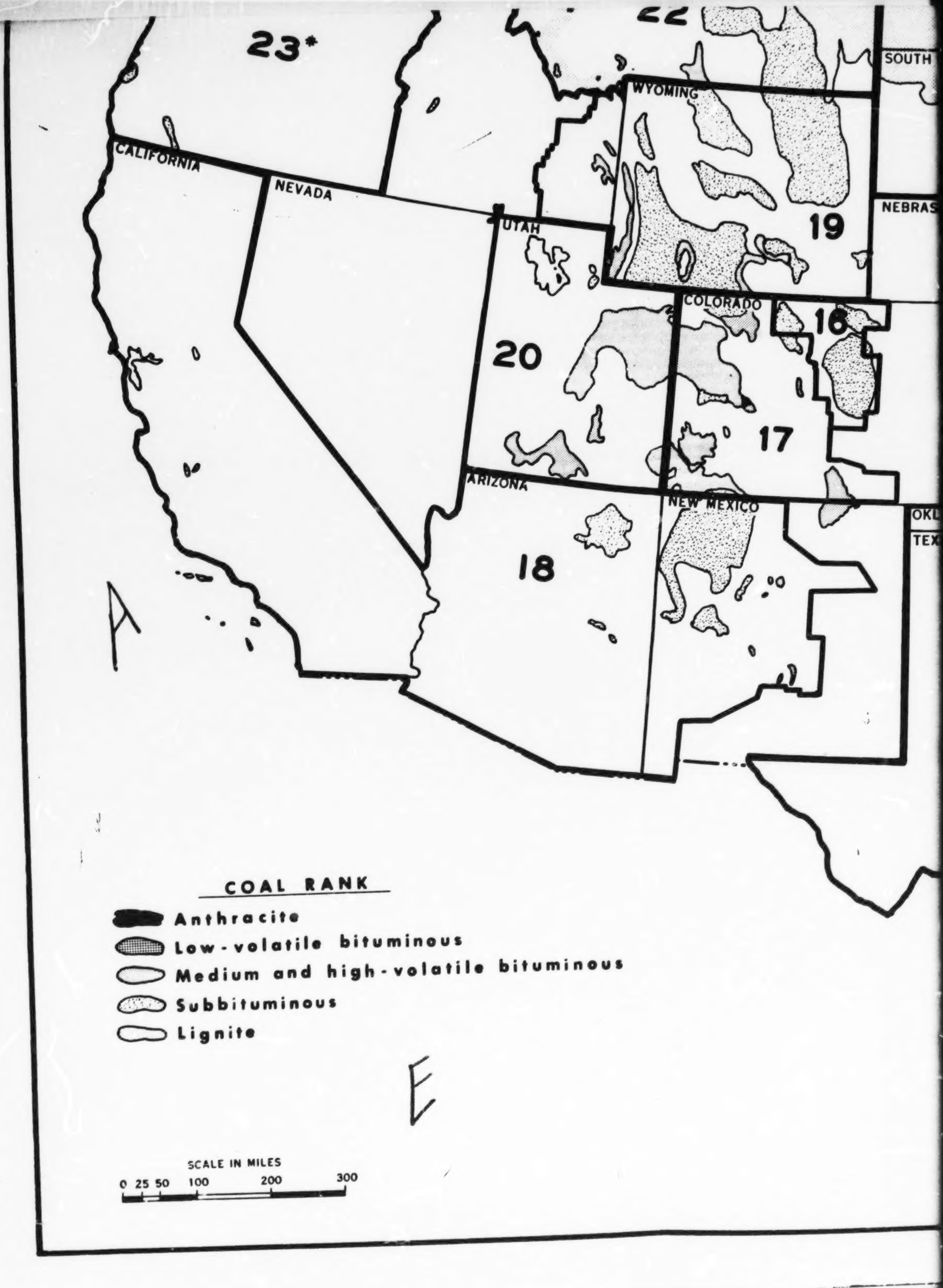
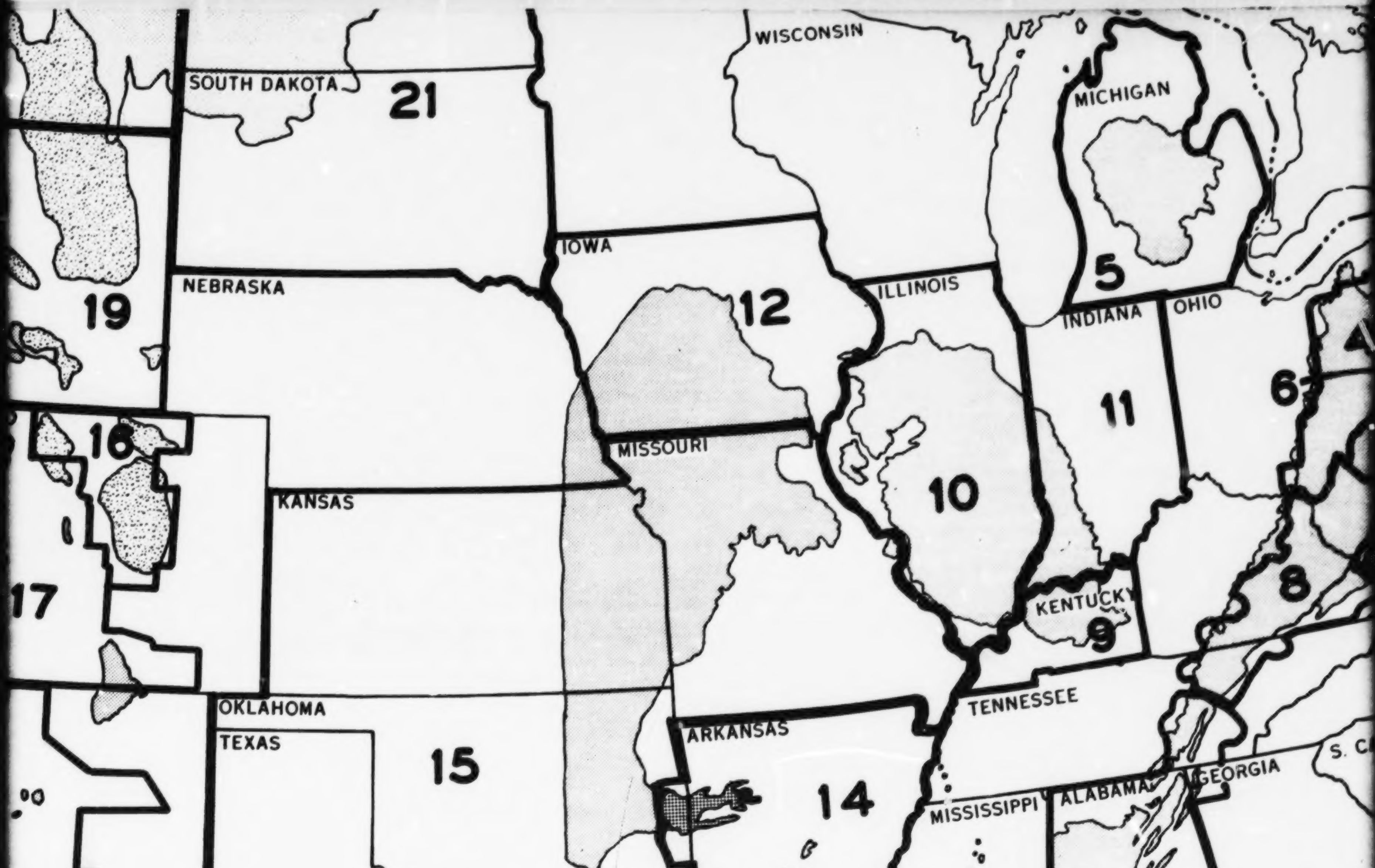
Bituminous coal producing district.
*District 23 includes Alaska.
Note: See Exhibit C.

COAL FIELDS
of the
UNITED STATES


23*
22
SOUTH
WYOMING
19
NEBRAS
CALIFORNIA
NEVADA
UTAH
20
COLORADO
16
17
ARIZONA
NEW MEXICO
18
OKL
TEX
A
COAL RANK
Anthracite
Low-volatile bituminous
Medium and high-volatile bituminous
Subbituminous
Lignite
E
SCALE IN MILES
0 25 50 100 200 300


SOUTH DAKOTA
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WISCONSIN
MICHIGAN
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NEBRASKA
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ILLINOIS
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ARKANSAS
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S. C
GEORGIA
ALABAMA
MISSISSIPPI
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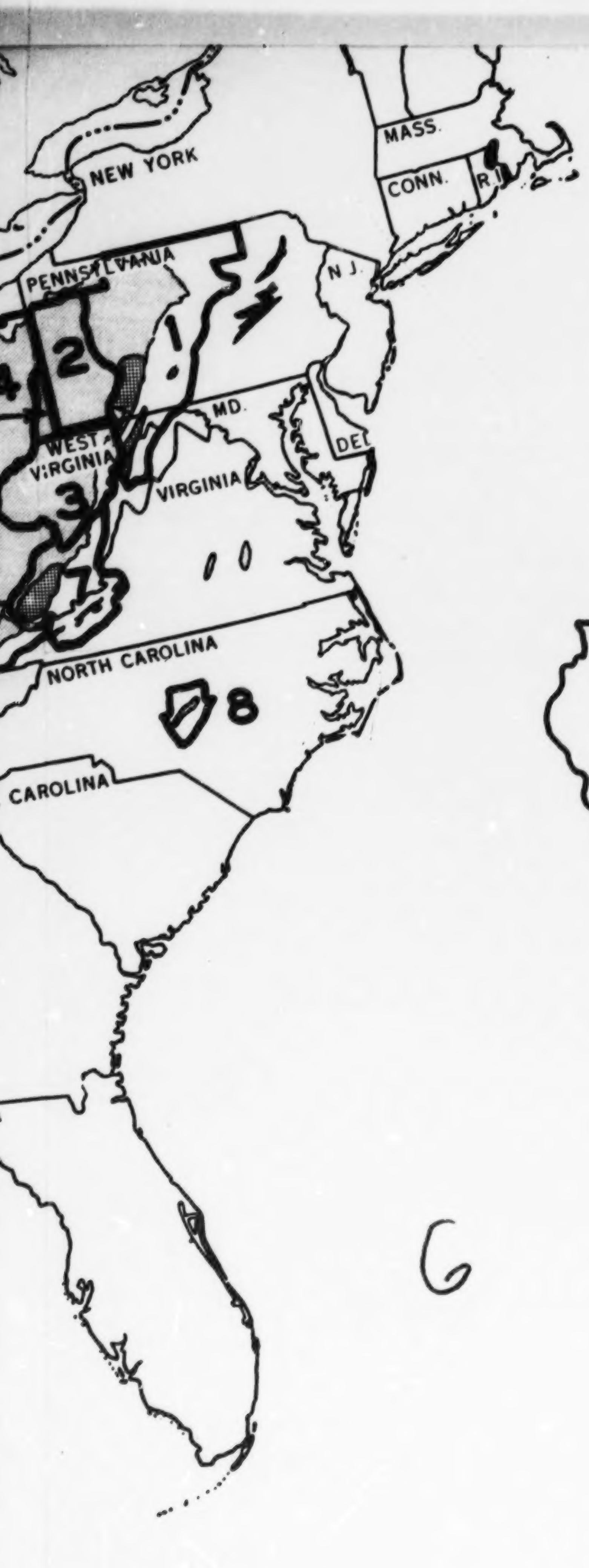
NEW YORK
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CAROLINA

10 Bituminous coal producing district.

*District 23 includes Alaska.

Note: See Exhibit C.

6

COAL FIELDS
# of the
UNITED STATES

PAUL WEIR COMPANY
INCORPORATED
MINING ENGINEERS AND GEOLOGISTS

Definition of Bituminous Coal
In Accordance with the B

DISTRICT 1.—EASTERN PENNSYLVANIA

Pennsylvania

Armstrong County (part).—All mines east of Allegheny River, and those mines served by the Pittsburgh & Shawmut Railroad located on the west bank of the river.

Fayette County (part).—All mines located on and east of the line of Indian Creek Valley branch of the Baltimore & Ohio Railroad.

Indiana County (part).—All mines not served by the Saltsburg branch of the Pennsylvania Railroad.

Westmoreland County (part).—All mines served by the Pennsylvania Railroad from Torrance, east.

All mines in the following counties:

Bedford
Blair
Bradford
Cambria
Cameron
Centre
Clarion
Clearfield
Clinton
Elk
Forest
Fulton
Huntingdon
Jefferson
Lycoming
McKean
Mifflin
Potter
Somerset
Tioga

Maryland.—All mines in the State.

West Virginia.—All mines in the following counties:
Grant Mineral Tucker

DISTRICT 2.—WESTERN PENNSYLVANIA

Pennsylvania

Armstrong County (part).—All mines west of the Allegheny River except those mines served by the Pittsburgh & Shawmut Railroad.

Fayette County (part).—All mines except those on and east of the line of Indian Creek Valley branch of the Baltimore & Ohio Railroad.

Indiana County (part).—All mines served by the Saltsburg branch of the Pennsylvania Railroad.

Westmoreland County (part).—All mines except those served by the Pennsylvania Railroad from Torrance, east.

All mines in the following counties:

Allegheny
Beaver
Butler
Greene
Lawrence
Mercer
Venango
Washington

DISTRICT 3.—NORTHERN WEST VIRGINIA

West Virginia

Nicholas County (part).—All mines served by or north of the Baltimore & Ohio Railroad.

All mines in the following counties:

Barbour
Braxton
Calhoun
Doddridge
Gilmer
Harrison
Jackson
Lewis
Marion
Monongalia
Pleasants
Preston
Randolph
Ritchie
Roane
Taylor
Tyler
Upshur
Webster
Wetzel
Wirt
Wood

DISTRICT 4.—OHIO.—All mines in the State.

DISTRICT 5.—MICHIGAN.—All mines in the State.

DISTRICT 6.—PANHANDLE

West Virginia.—All mines in the following counties:
Brooke Hancock Marshall Ohio

DISTRICT 7.—SOUTHERN NO. 1

West Virginia

Fayette County (part).—All mines east of Gauley River and all mines served by the Gauley River branch of the Chesapeake & Ohio Railroad and mines served by the Virginian Railway.

McDowell County (part).—All mines in that portion of the county served by the Dry Fork branch of the Norfolk & Western Railroad and east thereof.

Raleigh County (part).—All mines except those on the Coal River branch of the Chesapeake & Ohio Railroad and north thereof.

Wyoming County (part).—All mines in that portion served by the Gilbert branch of the Virginian Railway lying east of the mouth of Skin Fork of Guyandot River and in that portion served by the main line and the Glen Rogers branch of the Virginian Railway.

All mines in the following counties:
Greenbrier Mercer Monroe Pocahontas Summers

Virginia

Buchanan County (part).—All mines in that portion of the county served by the Richlands-Jewell Ridge branch of the Norfolk & Western Railroad and in that portion on the headwaters of Dismal Creek east of Lynn Camp Creek (a tributary of Dismal Creek).

Tazewell County (part).—All mines in those portions of the county served by the Dry Fork branch to Cedar Bluff and from Bluestone Junction to Boissevain branch of the Norfolk & Western Railroad and Richlands-Jewell Ridge branch of the Norfolk & Western Railroad.

All mines in the following counties:
Montgomery Pulaski Wythe Giles Craig

DISTRICT 8.—SOUTHERN NO. 2

West Virginia

Fayette County (part).—All mines west of the Gauley River except mines served by the Gauley River branch of the Chesapeake & Ohio Railroad.

McDowell County (part).—All mines west of and not served by the Dry Fork branch of the Norfolk & Western Railroad.

Nicholas County (part).—All mines in that part of the county south of and not served by the Baltimore & Ohio Railroad.

Raleigh County (part).—All mines on the Coal River branch of the Chesapeake & Ohio Railroad and north thereof.

Wyoming County (part).—All mines in that portion served by the Gilbert branch of the Virginian Railway and lying west of the mouth of Skin Fork of Guyandot River.

All mines in the following counties:

Boone
Cabell
Clay
Kanawha
Lincoln
Logan
Mason
Mingo
Putnam
Wayne

A

EXHIBIT C

tuminous Coal and Lignite Producing Districts
ce with the Bituminous Coal Act of 1937

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Giles Craig

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the Coal River
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in that portion
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ork of Guyandot

Wayne

Virginia

Buchanan County (part).—All mines in the county, except in that portion on the headwaters of Dismal Creek, east of Lynn Camp Creek (a tributary of Dismal Creek) and in that portion served by the Richlands-Jewell Ridge branch of the Norfolk & Western Railroad.

Tazewell County (part).—All mines in the county except in those portions served by the Dry Fork branch of the Norfolk & Western Railroad and branch from Bluestone Junction to Boissevain of Norfolk & Western Railroad and Richlands-Jewell Ridge branch of the Norfolk & Western Railroad.

All mines in the following counties:
Dickinson
Lee
Russell
Scott
Wise

Kentucky.—All mines in the following counties in eastern Kentucky:
Bell
Boyd
Breathitt
Carter
Clay
Elliott
Floyd
Greenup
Harlan
Jackson
Johnson
Knott
Knox
Laurel
Lawrence
Lee
Leslie
Letcher
McCreary
Magoffin
Martin
Morgan
Owsley
Perry
Pike
Rockcastle
Wayne
Whitley

Tennessee.—All mines in the following counties:
Anderson
Campbell
Claiborne
Cumberland
Fentress
Morgan
Overton
Putnam
Roane
Scott

North Carolina.—All mines in the State.

DISTRICT 9.—WEST KENTUCKY

Kentucky.—All mines in the following counties in western Kentucky:
Butler
Christian
Crittenden
Daviess
Hancock
Henderson
Hopkins
Logan
McLean
Muhlenberg
Ohio
Simpson
Todd
Union
Warren
Webster

DISTRICT 10.—ILLINOIS.—All mines in the State.

DISTRICT 11.—INDIANA.—All mines in the State.

DISTRICT 12.—IOWA.—All mines in the State.

DISTRICT 13.—SOUTHEASTERN

Alabama.—All mines in the State.

Georgia.—All mines in the following counties:
Dade
Walker

Tennessee.—All mines in the following counties:
Bledsoe
Grundy
Hamilton
Marion
McMinn
Rhea
Sequatchie
Van Buren
Warren
White

DISTRICT 14.—ARKANSAS-OKLAHOMA

Arkansas.—All mines in the State.

Oklahoma.—All mines in the following counties:
Haskell
Le Flore
Sequoyah

DISTRICT 15.—SOUTHWESTERN

Kansas.—All mines in the State.

Missouri.—All mines in the State.

Oklahoma.—All mines in the following counties:
Coal
Craig
Latimer
Muskogee
Okmulgee
Pittsburg
Rogers
Tulsa
Wagoner

DISTRICT 16.—NORTHERN COLORADO

All mines in the following counties in the State:
Adams
Arapahoe
Boulder
Douglas
Elbert
El Paso
Jackson
Jefferson
Larimer
Weld

DISTRICT 17.—SOUTHERN COLORADO

Colorado.—All mines except those included in District 16.

New Mexico.—All mines except those included in District 18.

DISTRICT 18.—NEW MEXICO

New Mexico.—All mines in the following counties:
Grant
Lincoln
McKinley
Rio Arriba
Sandoval
San Juan
San Miguel
Santa Fe
Socorro

Arizona.—All mines in the State.

California.—All mines in the State.

DISTRICT 19.—WYOMING

Wyoming.—All mines in the State.

Idaho.—All mines in the State.

DISTRICT 20.—UTAH.—All mines in the State.

DISTRICT 21.—NORTH DAKOTA-SOUTH DAKOTA.—All mines in North Dakota and South Dakota.

DISTRICT 22.—MONTANA.—All mines in the State.

DISTRICT 23.—WASHINGTON

Washington.—All mines in the State.

Oregon.—All mines in the State.

Alaska.—All mines in the Territory.

B